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EFFECT OF TRIETHANOLAMINE ON THE PROPERTIES OF PALM-BASED FLEXIBLE POLYURETHANE FOAMS

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ABSTRACT

This paper describes the effect of triethanolamine (TEA) on the properties, especially the strength properties, of flexible polyurethane foams produced from two palm-based polyols and modified methylene diphenyl diisocyanate (MDI). A commercial sample (visco elastic foam, CF1) was used as the control.

The properties evaluated were tack free time, density, percentage open-cell content, relative energy absorption, compressive stress and tear strength. The results were compared to a commercial sample. Incorporation of TEA improved the tack free time, percentage open-cell content and softness of the foams but not the tear strength. The foams formulated from polyol RD-PG31 had better properties than those from mixed polyol (50:50 RD-PG31:RD-PG51). The palm-based visco elastic foams are suitable for applications which require good dampening but in which strength is not of paramount importance, such as packaging and shock-absorption.

Keywords: flexible polyurethane foams, lazy foam, triethanolamine, palm oil, polyol.

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INTRODUCTION

The use of renewable resources to substitute for petrochemicals in many applications has gained considerable importance lately due to the supply and cost of the raw materials. The polymer industry, especially in the manufacture of polyurethane, has shown particular interest in this, and there have been several attempts to produce the raw materials, such as polyol and isocyanate, from natural oils instead of petroleum. In Malaysia, the cheap and abundant supply of palm oil begs for its use in the production of polyurethane foam. In the Malaysian Palm Oil Board (MPOB), research on the production of palm oil-based polyol started in 1982. Recently, a pilot plant with a capacity of 800 kg batch^{-1} palm-based polyol for the production of semi-rigid and flexible foam was commissioned.

An earlier study (Salmiah, 2001) indicated that palm-based polyols can be used for semi-rigid and rigid foams for insulators, and wall and ceiling panels. The major use of polyol, however, is in applications which require flexible foam. Using palm-based polyols alone, only visco elastic (lazy) foam can be made instead of flexible polyurethane foam. But visco elastic foam lacks strength, which can be improved by increasing the cross-linking within the polyurethane polymer network.

TEA is commonly used as a cross-linker in polyurethane (Wirpsza, 1993). By adding TEA, the cross linkage is improved for better strength without much compromising the other desirable properties. Although at high concentration TEA is a cross-linker, in low concentration, especially in the presence of stannous compounds, it is only a co-catalyst speeding the rate of the reaction (Oertel, 1985).

Due to the use of TEA, the formulations could also have affected the rate of reaction and therefore, the characteristics of the polyurethane. Thus, in this study, only the polyols and TEA were varied while the rest of the additives were kept constant.

This paper reports the effects of adding TEA on the properties of flexible foams made from palm-based polyols in the pilot plant. The incorporation

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of TEA as a cross-linking agent is expected to improve the properties of the flexible foams, especially their strength and flexibility.

EXPERIMENTAL

Materials

The palm-based polyols, RD-PG31 and RD-PG51, were obtained by reacting palm oil with various polyhydric alcohols in the MPOB/InterMed pilot plant (Salmiah, 2001). The process for the production of polyols has been patented in Malaysia (PI 9502302) and Singapore (55223) and is pending in Indonesia (patent application, P962884). The properties of the polyols are shown in *Table 1*.

TABLE 1. PROPERTIES OF PALM-BASED POLYOLS FROM THE PILOT PLANT

Polyol / Property	RD-PG31	RD-PG51
Hydroxyl value (mg KOH g^{-1})	117.5	131.6
Molecular weight	4 638	4 539
Functionality	2	2

Additives such as Niax A33, stannous octoate (Witco Corporation), TEA (BASF Malaysia), surfactant (L-603, Witco Corporation) and modified methylene diphenyl diisocyanate (MDI, Cosmonate MC-73, Cosmo Polyurethane) were incorporated in the formulations. Distilled water was used as the blowing agent.

Foam Preparation

The foam formulations were divided into two series depending on the type of polyols used: (a) 100% RD-PG31, and (b) 50:50 v/v RD-PG31 and RD-PG51. Pure RD-PG51 had previously produced low quality flexible foam and it was not further investigated. In each formulation, a different amount of TEA was incorporated. The foams were prepared by adding modified MDI to the polyol blend which consisted of polyol, surfactant, Niax A33, TEA, stannous octoate and distilled water followed by vigorous mixing (stirring at 2000 rpm for 1 min).

At the creaming stage (the mixture turning creamy), the mixture was poured into a polyethylene tray of 40 cm x 30 cm x 9 cm and allowed to rise freely. The tack free time was recorded. After this, the foam was removed from the tray and allowed to cure for one day before cutting into the test specimens.

PROPERTIES OF THE POLYURETHANE FOAMS

Tack Free Time

This was the time between pouring the isocyanate into the polyol blend and the point when the outer skin of the foam mass was no longer sticky to the finger on gentle touching.

Density

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

Open-Cell Content

This was the percentage of permeable structure in the foam without any barriers between the cells and in which gasses can circulate freely. A Micromeritics AccuPyc 1330 Pycnometer was used to determine the volume in the sample blocks based on the pressure change of nitrogen on a calibrated volume. Two cubes (25 mm x 25 mm x 25 mm) of a sample were placed in the cylinder and the gas displacement volume (V_{p1}) determined. Then, each cube was cut into eight smaller cubes. All the small cubes were placed in the cylinder and the volume taken again (V_{p2}). The open-cell content was derived by:

$$\text{Volume of open cells, } V_\alpha = V_g - 2V_{p1} + V_{p2},$$

where $V_g = 31.25\ cm^3$ (geometric volume of samples).

Thus, the percentage of open cell content (Co) = $(V_\alpha/V_g) \times 100$.

Relative Energy Absorption

This was the hysteresis area (from loading and unloading) plotted on the stress versus strain curve during the compression hardness test according to

DIN ISO 3386. A piece of foam of 100 mm x 100 mm x 50 mm was compressed between two flat plates at a rate of 50 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 procedures were repeated three times. The reading of relative energy absorption was recorded. Three samples were tested and the mean derived. The instrument used was a Zwick Universal Testing Machine with crosshead monitor and compression platens as the grip.

Compressive Stress

This was the hardness at 40% strain from the compression hardness test. The test was conducted according to DIN ISO 3386. A piece of foam of 100 mm x 100 mm x 50 mm was compressed between two flat plates at a rate of 50 mm min^{-1} until 70% of its original thickness. 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 procedures were repeated three times and the force at 40% strain, at the fourth compression cycle, recorded. The stress at 40% strain was calculated. Three samples were tested and the mean derived.

Tear Strength

The test was conducted according to ASTM 3574 – Method F using the Zwick Universal Testing Machine with crosshead monitor and a pincer as the grip. The samples used were 25 mm x 25 mm in cross-section and 125 mm long. Each sample was split in the middle along its length to a depth of 40 mm. The cut edges of the specimen were held and pulled apart at a rate of 50 mm min^{-1}. The maximum force (tear strength) registered on the testing machine was recorded. Three specimens per sample were tested and the mean derived.

RESULTS

Density

For both the polyols (RD-PG31 and mixed polyol), the density of the foam increased with the amount of TEA added (*Figure 1*). However, with 100% RD-PG31 the density increased more so that the foams produced were of a slightly higher density. The density of the control commercial sample (which was for visco elastic contour pillows) was slightly higher than those of the palm-based foams. Generally, the density of the foam required is dictated by its intended use – for cushions and mattresses, the minimum should be 30-35 kg m^{-3} (Oertel, 1985), and for packing, normally 15-30 kg m^{-3} depending on the goods to be packaged (Oertel, 1985).

Tack Free Time

As shown in *Figure 2*, the tack free time of the foams was reduced with increasing TEA because of more cross-linking. At low concentrations, TEA only acts as a build co-catalyst to the tertiary amine/Sn

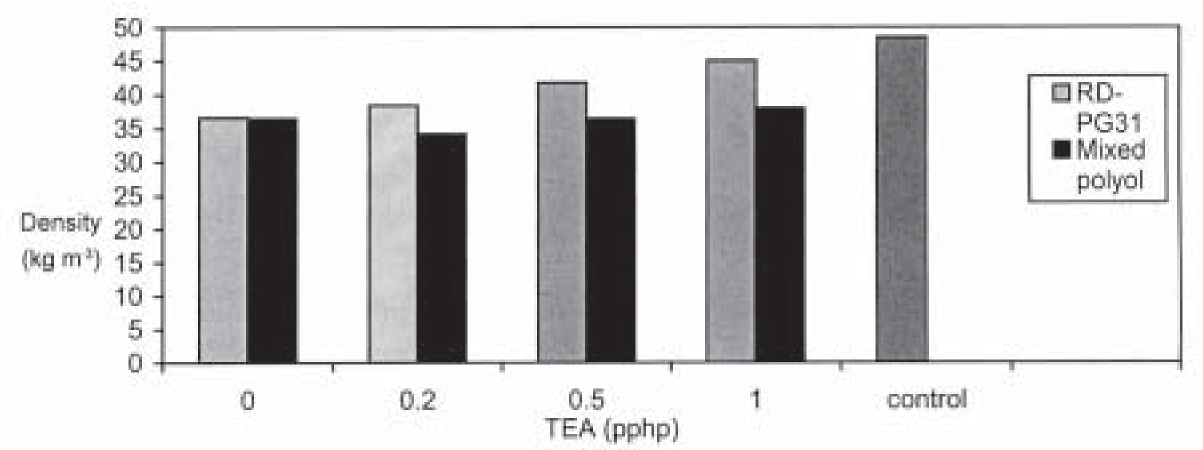

Figure 1. Effect of triethanolamine (TEA) on the density of polyurethane foam produced from RD-PG31 and mixed polyols.

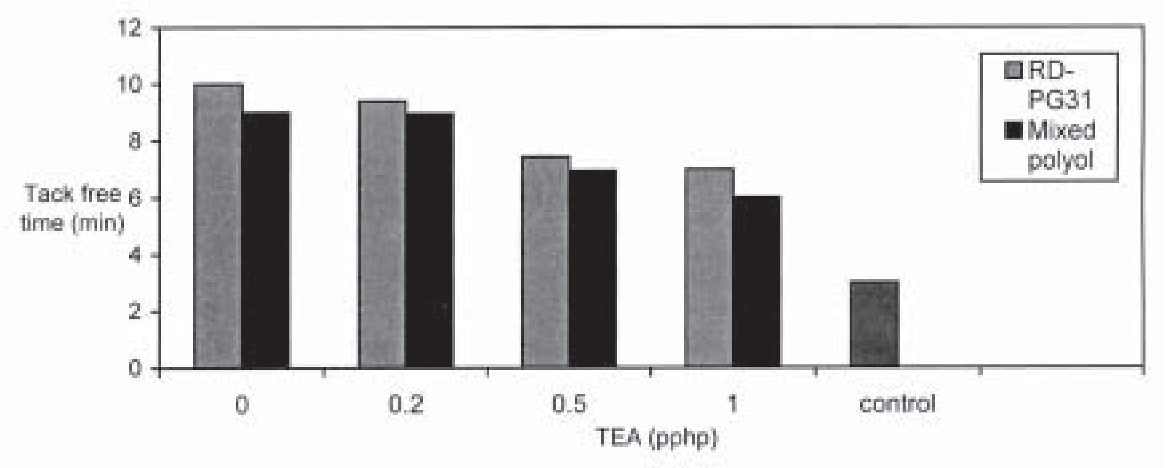

Figure 2. Effect of triethanolamine (TEA) on the tack free time of polyurethane foam produced from RD-PG31 and mixed polyol.

catalyst. However, at higher concentrations, it acts as a cross linker (Oertel, 1985). The tack free time of foams formulated with mixed polyol decreased faster than those formulated with RD-PG31. However, the control had yet a shorter time. The tack free time is an important property in manufacture as it has a direct impact on the production capacity.

Percentage Open Cell Content

The open cells allow air to permeate through the foam resulting in better comfort or sound proofing. A high percentage of open cells is required for products such as mattresses, cushions and sound-insulators. From *Figure 3*, the percentage open-cell for foams formulated with mixed polyol was much lower than that of the foams formulated with RD-PG31 at the same concentration of TEA. TEA increased the open-cell content of the foams, especially those made with RD-PG31 which had almost the same content as the control foam. This was an opposite effect to the cross-linkage as increasing the linkage decreases the number of open cells. Thus, in a foam formulation, there must be a balance between the catalyses for the blowing and cross-linking reactions (Oertel, 1985).

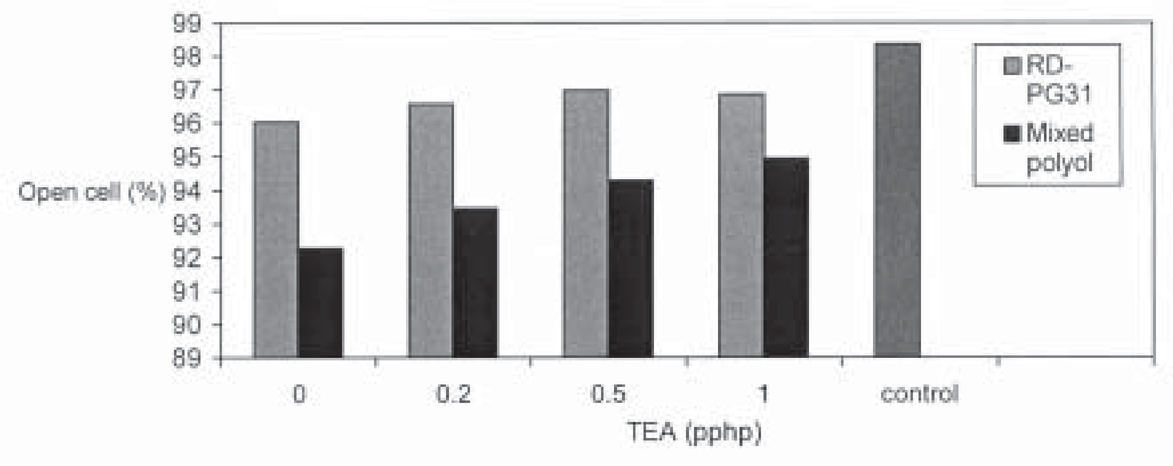

Figure 3. Effect of triethanolamine (TEA) on percentage open-cell content of polyurethane foam produced from RD-PG31 and mixed polyol.

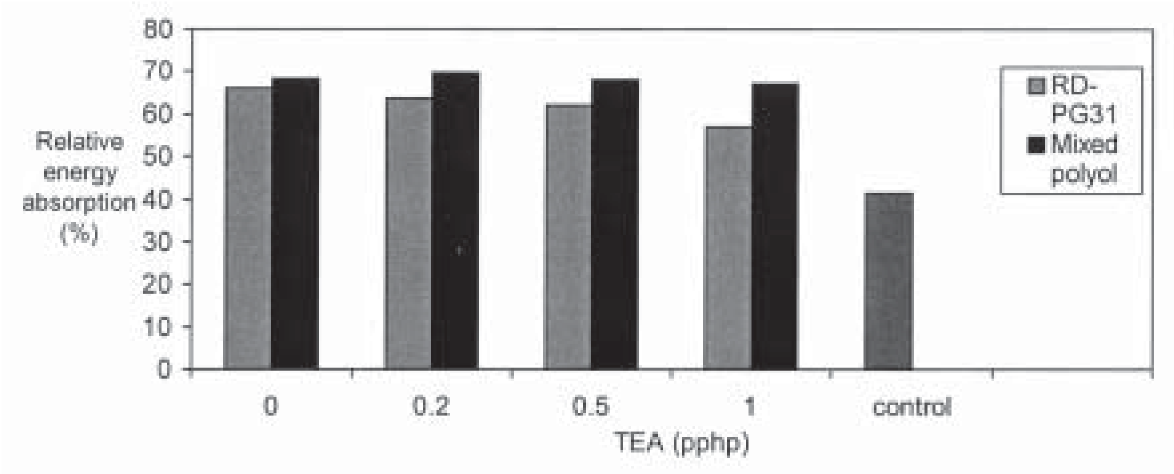

Figure 4. Effect of triethanolamine (TEA) on relative energy absorption of polyurethane foam produced from RD-PG31 and mixed polyol.

Relative Energy Absorption

Figure 4 shows that the palm-based foams had higher relative energy absorption than the control foam. This higher damping behaviour suggests that they will be good sound and vibration insulators (Wirpsza, 1993). Although TEA only slightly reduced the relative energy absorption, the effect was more pronounced on the foams formulated with RD-PG31. The foams from mixed polyol showed much higher energy absorption than those from RD-PG31. The higher energy absorption by the palm-based flexible foams suggests their potential applications in packing materials and cushions.

Compressive Stress

The compressive stress measures the softness of the foam. Besides density, hardness is an important characteristic of flexible foam. The softer the foam, the greater is its comfort. *Figure 5* shows that the compressive stress of the palm-based foams was higher than that of the control. Increasing TEA decreased the compressive stress for all the formulations, especially for the foams from RD-PG31. This shows that TEA softens foam.

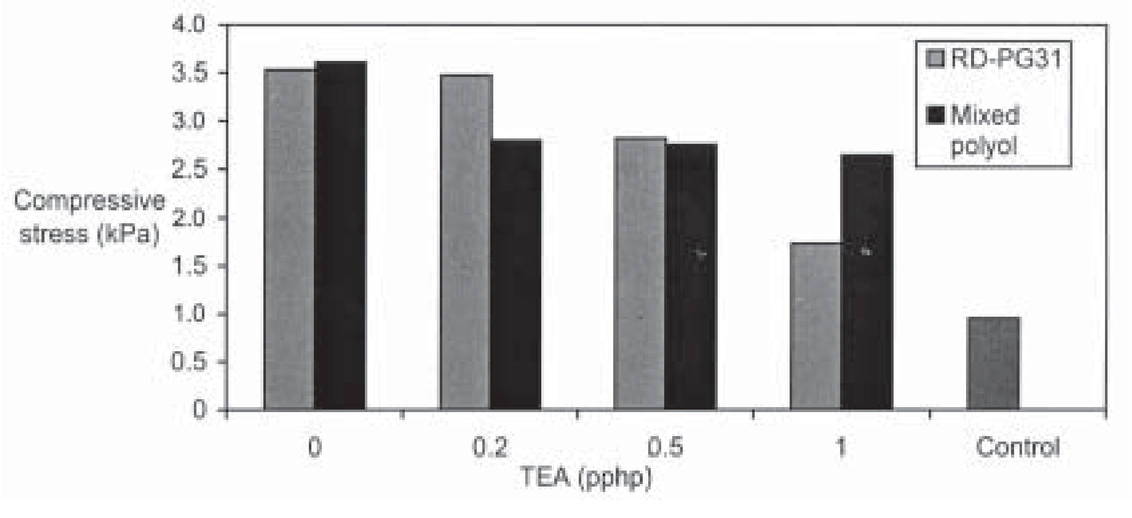

Figure 5. Effect of triethanolamine (TEA) on the compressive stress of polyurethane foam produced from RD-PG31 and mixed polyol.

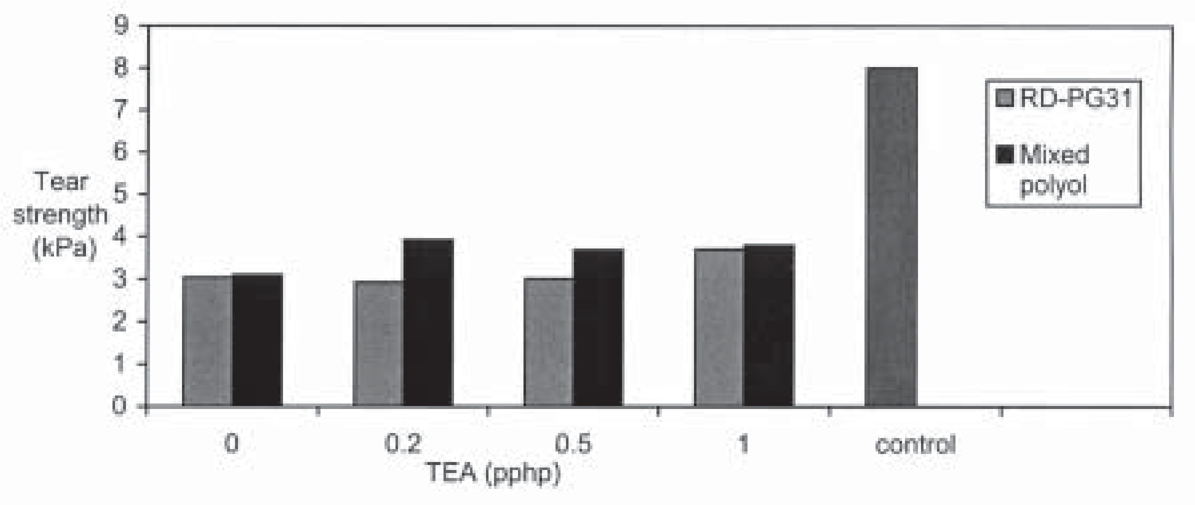

Figure 6. Effect of triethanolamine (TEA) on the tear strength of polyurethane foam produced from RD-PG31 and mixed polyol.

Tear Strength

Figure 6 shows the superior strength of the control foam over the palm-based foams. The tear strength for the palm-based foams was 3-5 kPa while that of the control foam almost 8 kPa. Thus, the palm-based flexible foams are only suitable for applications requiring low strength, such as packaging and shock absorption materials.

DISCUSSION

The palm-based polyol, RD-PG51, did not produce good lazy foam. The RD-PG31 and mixed polyol, on the other hand, produced good lazy foams but which lacked strength. Adding TEA to the formulations decreased the tack free time and compressive stress and increased the open-cell content. These are desirable effects as decreasing the tack free time will increase the throughput in production, increasing the open-cell content will impart better insulation, and decreasing the compressive stress will improve the softness. However, TEA also had the disadvantages of increasing the density (increasing the cost), and decreasing the energy absorption but no effect on the tear strength.

CONCLUSION

Incorporating TEA improved the tack free time, percentage open-cell content and softness of palm-based visco elastic foams as compared to the foam without TEA but not the tear strength. It was also showed that foams formulated from the palm-based polyol, RD-PG31, had better properties than the foams from mixed polyol. The palm-based visco elastic foams are expected to be suitable for applications which require good dampening but in which strength is not of paramount importance, such as, packaging, shock-absorption, *etc*. However, the efforts to improve their tear strength will continue.

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