

## Optimization of polyurethane lightweight aggregate with the addition of palm-based polyol

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**Abstract.** Lightweight aggregate for concrete was produced by utilizing palm-based polyurethane (PU) as a substantial material. New types of green PU were prepared by reacting palm kernel oil polyol (PKO-p) with 2, 4-methylene diphenyl diisocyanate (crude MDI). Six attempts on rigid PU were investigated to determine the reaction time, density, compressive strength, and thermal conductivity. An additional polyol showed high density between 200-300 kg/m<sup>3</sup>. The compressive strength and thermal conductivity improved to 11.5 MPa and 0.060 W/mK, respectively. As a conclusion, the results of palm-based PU showed excellent properties established the lightweight aggregate and insulation material in the concrete technology.

### Introduction

Petrochemical resources have been used extensively worldwide in the chemical industry, particularly for expanded polystyrene (EPS) and polyurethane (PU) productions. These sources are now limited and have been depleting. They are also experiencing price instability. In the PU industry, polyols and isocyanates are two major ingredients used, and both are derived from petroleum. Vegetable oil and fat are alternative sources for polyols. Vegetable oils, like soybean oil, sunflower oil, palm oil, olive oil, and linseed oil, with a worldwide production of about 127 million tons in 2007, have been used mainly in food applications (76%), while 19.5% account for technical applications, and 1.5% for other applications [1].

This study presents the usage of a natural, renewable, and sustainable material, namely palm kernel oil polyol (PKO-p), as a substitute to petroleum-based polyols in the PU industry. Badri [2] had successfully produced and developed a palm-based PU for wide applications, such as rigid foam, elastomer, coating, adhesive, and sealant. The PU system consists of PKO-p and 2, 4-methylene diphenyl diisocyanate (crude MDI). Polyisocyanate acts as the polymerizing agent to the polyol. Thus, urethane and related forms are recognized as building block polymers [3].

The high density PU foam able to achieve higher compressive strength compared to low-density PU. Hirose et al. [4] reported that a good specimen of PU with low density of 40-50 kg/m<sup>3</sup>, subject of the application. Mark Sonnenschein et al. [5] and Gonzalez Gutierrez et al. [6] reviewed on waste PU with the density of 45-131 kg/m<sup>3</sup> and 68-72 kg/m<sup>3</sup>, respectively. Then, Mounanga et al. [7] used fine aggregated density of 45 kg/m<sup>3</sup> with smaller size than or equal to 10 mm in lightweight concrete. On the other hand, Vaclavik et al. [8] investigated the effect of thermal modification of mortar with 30-50 kg/m<sup>3</sup> density PU waste as filler.

The purpose of this study was to determine the PU optimum proportion with additional PKO-p by volume, where MDI was kept constant. The properties of palm-based PU were also investigated, such as density, compressive strength, and thermal conductivity.

## Experimental Study

**Materials.** The PKO-p was supplied by UKM Technology SdnBhd through Badri's[9] pilot plant at MPOB Bangi Lama, Selangor, Malaysia. The PKO-p was synthesized by polyesterification and a polycondensation process [2]. The chemical used for the prepolymerization of PU foam was crude MDI (2,4-methylene diphenyldiisocyanate) from Cosmopolyurethane (M) Sdn Bhd, Port Klang, Malaysia.

**Mix Proportions.** Six ratios of PU were studied with sample A as the control. The other samples were mixed with an additional 20 % of PKO-p. The mixture was stirred using a mechanical stirrer at 1000 rpm for 10 s. The mixture was then poured into a screw-tight mould, and was allowed to cure for 10 min. The ratio of PKO-p resin to MDI was optimized prior to identifying the density and the stage of reaction. During the polymerization, the reaction time; cream time (CT), rise time (RT), and hardening time (HT) [3], were observed and recorded. Once demoulded, the PU foam was left to condition at room temperature for 16 h before further characterizations, such as density, compressive strength, and thermal conductivity were looked into.

## Characterization

The foam density was determined following BS4370: Part 1: 1988 Method 2 by applying the equation of mass, kg divided by volume, m<sup>3</sup>. Foam samples were prepared via moulding technique into cubes of 50 mm × 50 mm × 50 mm in dimension. Three samples were used and were carefully weighed using an analytical balance.

The compression test for PU was conducted according to BS 4370: Part 1: 1988: Method 3. The samples were cut to the dimension of 50 mm × 50 mm × 50 mm. The test was carried out using Instron Universal Testing Machine model 5566 at a cross-head speed of 50 mm/min until the thickness was reduced to 10% of its original thickness. The compressive stress was recorded as the average for five specimens.

The thermal conductivity was conducted using the Heat Flow Meter HFM 436 Lambda, following ASTM C518. The samples of rigid PU foam were prepared via moulding technique using a thick plate of 300 mm × 300 mm × 25 mm and analyzed at the temperature of 20°C.

## Results and Discussion

**Reaction time.** Table 1 shows the data that determined the optimal parameters in the production of rigid PU. The optimization was done by accessing PKO-up, while MDI was maintained. Each sample was increased by 20% PKO-p. A total of six experiments were carried out, with the addition of PKO-p. From the experiments, only samples A, B, and C performed complete PU in rigid foam. Meanwhile, samples D, E, and F were incomplete as the soft segment exceeded the hard segment. From the observation, the mixture formed a long chain of polyol, viscous, and sticky form. Therefore, no hardened time was recorded.

Table 1 Optimization of PU by varying PKO-p

Sample	PU ratio		CT (s)	RT (s)	HT (s)
	PKO-p	MDI			
A	50.0	50.0	70	86	240
B	54.5	45.4	64	99	330
C	58.3	41.6	62	102	483
D	61.5	38.5	63	96	-
E	64.3	35.7	65	90	-
F	66.6	33.3	66	100	-

\* CT: Cream time, RT: Rise time, HT: Hardened time

The reaction time for all the samples was relatively extensive. After stirring for 10 s, the results showed that the cream time and rise time were almost 60 s and 100 s, respectively. The time process

of polymerization was influenced by a triggering substance used in the mixtures [10]. Generally, in the production of industrial PU, blowing agents, surfactant, and catalyst have been used.

**Density.** PU based on palm kernel oil (PKO) had higher density compared to PU in the industry ( $40\text{--}60\text{ kg/m}^3$ ). The density was between  $200\text{ kg/m}^3$  to  $400\text{ kg/m}^3$ , depending on the materials composition. This density is classified as high-density rigid PU [10]. Table 2 shows the significant modifications of density for three ratios of PU. The density of control PU foam was  $206\text{ kg/m}^3$ . With the addition of 20% PKO-p in the MDI, the density was increased up to 9.2%. The increase was due to the increased polyol crosslink that caused long range linkages [2]. The density of PU is interconnected with the compression strength and thermal conductivity [11].

Table 2 Properties of rigid PU

Sample	Density ( $\text{kg/m}^3$ )	Compressive strength (MPa)	Thermal conductivity (W/mK)
A	206	7.0	0.052
B	225	9.3	0.053
C	266	11.5	0.062

**Compressive strength.** The compressive strength of PU was proportional to the density, as seen in Fig. 1. Density is a key factor that influences the compressive strength. Higher density performs higher compressive strength [12]. The addition of PKO-p increased the compressive strength of 7 MPa (sample A) to 11.5 MPa (sample C). The compressive strength of rigid PU was increased up to 39.1%. The modification existed due to the presence of soft and hard segments in the PU. Hence, more soft segments and cross linking were produced by increased addition of PKO-p. The hard segment from the MDI created short linkages, and loose and brittle cross-bonding between the materials. Therefore, the compression strength was lower.

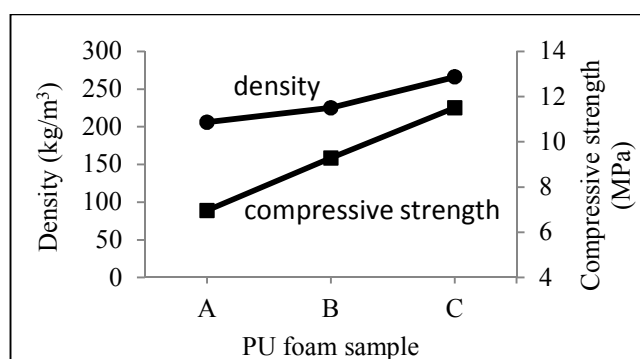


Fig. 1 The effects of density and compressive strength on PU foam sample.

**Thermal conductivity.** The high density of rigid PU developed high thermal conductivity value [13]. Fig. 2 shows the effect of palm-based PU on thermal conductivity for samples A, B, and C. A Heat Flow Meter was used to set the temperature at  $20^\circ\text{C}$ . The graph shows that with the increase in the amount of PKO-p, higher thermal conductivity was achieved in accordance with the density. Sample A (density  $206\text{ kg/m}^3$ ) indicated the lowest thermal conductivity of  $0.0518\text{ W/mK}$ . Therefore, with the addition of 20% of PKO-p to samples B and C, the values increased to  $0.0533\text{ W/mK}$  and  $0.0619\text{ W/mK}$ , respectively.

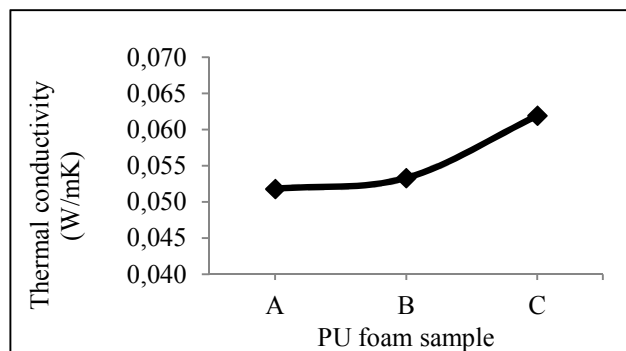


Fig. 2 The effects of thermal conductivity on palm-based PU at 20°C

A PU rigid form has over 90% closed cells and is classified to have a very low thermal conductivity and high compressive strength. The industrial PU (density of 30-100 kg/m<sup>3</sup>) produced thermal conductivity between 0.024 and 0.030 W/mK, and compressive strength of 100-150 kPa at 10% disability [14]. Lower thermal conductivity value implemented better thermal properties. Badri [2] conducted a study on palm-based PU with a density of 40-60 kg/m<sup>3</sup> and it attained low thermal conductivity; 0.025 W/mK. Although the thermal conductivity of rigid PU had been relatively higher compared to the industrial PU, nevertheless the compressive strength was practical as a lightweight aggregate. Thus, PU with compressive strength properties and good thermal conductivity is suitable to be implemented as an insulated lightweight aggregate.

## Conclusion

The optimal proportion of new lightweight aggregate using natural-based PU was sample A with the ratio of 1:1 (PKO-p:MDI). By additional percentage of PKO-p, contributes to a higher k-value, indicating an excellent thermal insulation properties. Besides, the palm-based lightweight aggregate portrayed excellent properties of compressive strength (11.5 MPa) and thermal conductivity (0.052 W/mK). In brief, the new alternative of palm-based PU utilized as a filler and proposed in the concrete technology, specifically for lightweight concrete and insulated materials.

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