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Research Article

Polyurethane Foam Production using Sunflower oil and Soybean oil as Polyol and Surfactant

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Abstract

In recent times, vegetable oils have shown promising characteristics in the replacement of petroleum-based chemicals. This is very attracting because they are inexpensive, readily available and most importantly renewable in nature hence reducing environmental pollution and degradation. Sunflower oil and soybean oil were blended with polyol and silicone oil in different percentages and were used to produce samples of flexible polyurethane foam as a partial replacement for polyol and silicone oil respectively. Physico-mechanical tests carried out on the various samples revealed that foam made with 15% soybean oil and 10% sunflower oil had outstanding properties which are very similar to a control sample (S_0) made with only silicone oil and polyol respectively.

Keywords: Flexible foam; Vegetable oil; Sunflower oil; Soybean oil; Elongation at break point; compression set.

Introduction

Polyurethane foams (PUFs) can be broadly divided into flexible foams (FFs) and rigid foams (RFs). Nevertheless, other classifications still include flexible polyurethane (PU) slabs, flexible molded foams, reaction injection molding, carpet backings, etc [1-2].

Generally, PUs are produced at the processing stage by the metering and mixing of two or more streams of liquid components containing PU precursors, and the relative amount of the precursors being used are usually tailored to the type of the product and to the production process [3-4]. The monomers used to form PUFs are organic isocyanates and polyols (including polyether and polyester polyols), which are majorly derived from the petrochemical refining of crude oil [5-6]. While the commonly used isocyanates are MDI and TDI, other additives such as catalysts, surfactants, pigments, etc are also usually added but in small quantities [4]. In PU production, the isocyanate reacts with the polyol, yielding urethane groups, and with water, yielding urea groups and CO_2. The urethane and urea moieties are associated with the hard segment of PUFs while, the polyol forms the soft segment [7].

Polyol is the largest percentage by weight of raw material used for PUF production. Petrochemical-based polyol posses the ability to induce outstanding mechanical characteristics in foam and are very expensive owing to the high cost of petrochemical feedstocks [8]. This in turn makes the cost of PUF high.

However, current sustainability studies geared towards developing green source materials as potential replacement for petroleum-based feedstocks have shown that some renewable vegetable oils have outstanding properties which can be harnessed in PUF production as polyols and surfactants [9].

In general, vegetable oils consist of triglycerides and small amounts of mono and diglycerides [10]. Sunflower oil is a polyunsaturated oil which has a high amount of linoleic acid [11]. Its seeds are very rich in oil (about 50% wt.), and from a chemical perspective, are considered very good for human consumption, because of its high ratio of

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polyunsaturated/saturated fatty acids and high linoleic acid contents [12-13].

Another outstanding raw material used in PUF production is the surfactant. A typical surfactant is a copolymer composed of silicone backbone. Its duties include lowering of the surface tension, emulsification of incompatible formulation ingredients, promotion of the nucleation of bubbles, stabilization of cells etc [14]. Soybean oil, one of the renewable vegetable oil have been reported to be emollient [15], a property that can be harnessed by PUF manufacturers as an inexpensive replacement for silicone compounds as surfactants.

Just like sunflower oil, soybean oil are edible [11], hence are popular for its use in food stuffs [16]. Soybean oil contains high polyunsaturated fatty acid. They are relatively inexpensive [15], environmentally friendly and most importantly renewable in nature [17]. In Africa, Nigeria has greatly improved in the production of soybean seeds. Other countries in Africa known for their remarkable soybean seed production include South Africa, Zambia, and Uganda [18].

It is imperative to state that the production of PUFs is still highly petroleum dependent. And considering the global restrictive regulations on environmental pollution due to various refining processes of petrochemical products, alternative raw materials for the production of PUFs obtained majorly from renewable resources must be given attention to and considered not just at the experimental level but at commercial level too. Flexible polyurethane foam was produced in this research using sunflower oil and soybean oil as replacement for petrochemical based polyol and silicone surfactant respectively. The characterization of the foam produced was outlined.

Materials and methods

Materials used

Polyol (PPG 3601), toluene diisocyanate (TDI) (UN 2078), tin catalyst, dimethyl ethyl amine (DMEA) (LV-33), silicone oil (L-620/PDR), and water, were gotten from the production department of Exotic Foam and Chemical Limited, Nkpor, Anambra State. Sunflower oil and soybean oil were purchased from Ose Market, Onitsha, Anambra State, Nigeria.

Equipment used

Volume box mould lined with cold water starch, MH887 electronic digital scale, manual stirrer, safety gloves, safety eye glass, stop watch, reaction container for mixing, beakers, syringes.

Method used

The density of the flexible foam used for this research work is 21kg/m^3 as formulated by Usman MA at al. [19]. All the raw materials was weighed in grams using the electronic scale and kept separately in various beakers. For the substitution of polyol, sunflower oil was added to the polyol and stirred properly for some minutes in order to ensure a thorough blend, before other raw materials were added and the foam produced.

While for the substitution of silicone oil, DMEA was added to the water, mixed properly and kept. Silicone oil was mixed with soybean oil and stirred. This was then poured into the water-DMEA mixture and the resulting mixture stirred properly. This was done in order to ensure a thorough miscibility of water, DMEA, silicone oil and soybean oil.

Polyol (and sunflower oil, as the case maybe) was poured into the reaction container and followed by tin catalyst. This was stirred. Water-DMEA-silicone oil and soybean oil (as the case may be) was added as the stirring continued. TDI was added last and the mixture stirred for some seconds before discharging into the volume box mould. The mixing immediately after the addition of TDI was very important because it helps to prepare coagulation of some chemicals and also to input atmospheric air into the mixture, which in turn helps to open the cells [5]. The rise time and gell time was noted. The foam sample was removed and aerated for about 18 hours to ensure complete curing before characterization [5]. The box mould and reaction container were cleaned and set for another batch of production.

Experimental procedure

The experimental procedure was designed in the same way as that of Aremu MO et al. [5]. Five different batches of foams were produced for the silicone oil substitution, while four different batches were produced for the polyol substitution. The experimental procedure was designed such that as there was a gradual decrease in percentage of polyol and silicone oil, there was a corresponding increase in the percentage of the substituting chemicals; sunflower oil and soybean oil respectively for the various batches. The formulation for the substitution of polyol and silicone oil with sunflower oil and soybean oil is shown in table 1 and 2 respectively.

Table 1. Experimental formulation for polyol substitution with sunflower oil

Raw materials (g)	S_0	S_a	S_b	S_c	S_d
Sunflower oil percentage (%)	0	5	10	15	20
Polyol	1000	950	900	850	800
Sunflower oil	0	50	100	150	200
Tin catalyst	2	2	2	2	2
Water	42	42	42	42	42
Silicone oil	10	10	10	10	10
DMEA	0.8	0.8	0.8	0.8	0.8
TDI	516	516	516	516	516

Table 2. Experimental formulation for the substitution of silicone oil with soybean oil

Raw materials (g)	S_0	S_1	S_2	S_3	S_4	S_5
Soybean oil percentage (%)	0	5	10	15	20	25
Polyol	1000	1000	1000	1000	1000	1000
Tin catalyst	2	2	2	2	2	2
DMEA	0.8	0.8	0.8	0.8	0.8	0.8
Silicone oil	10	9	8	7	6	5
Soybean oil	0	1	2	3	4	5
Water	42	42	42	42	42	42
TDI	516	516	516	516	516	516

Results and discussion

Physical tests carried out on the silicone substitution with soybean oil and polyol substitution with sunflower oil are presented on tables 3 and 4 respectively.

Results of silicone oil substitution with soybean oil

In fig. 1, there is a progressive decrease in rise time from S_0 to S_3 and then a sharp increase to S_5. This trend is in accordance to what [5] reported. This implies that the blowing/gas production reaction between TDI and water was fastest in S_3, and therefore infers that the substitution of 15% of silicone oil with soybean oil influences rise time which is a positive development.

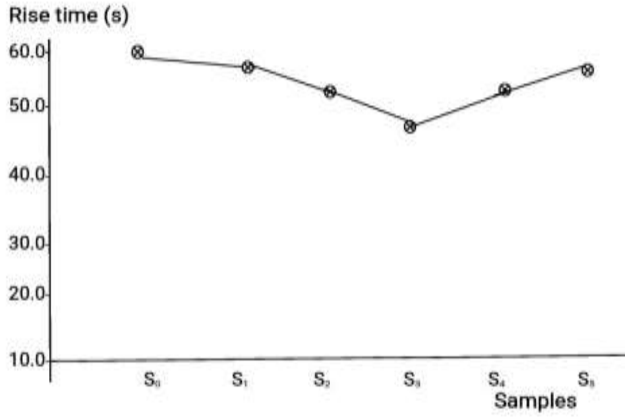

Fig. 1. Rise time for silicone oil substitution with soybean oil

From table 3, the gell time reduced drastically from S_0 to S_1 and then slowly to S_4. However, there was a sharp increase in S_5. The reduction in gell time from S_0 to S_4 shows that the demoulding time also reduces. This implies that the foam produced can be quickly retracted from the mould and is another positive development.

Table 3. Results of physico-mechanical tests on silicone oil substitution with soybean oil

	S_0	S_1	S_2	S_3	S_4	S_5
Density (kg/m^3)	21.12	21.56	35.65	22.91	23.04	25.08
Rise time (s)	60	56	52	46	52	55
Compression set (%)	5.30	5.26	3.12	3.01	5.28	8.35
Elongation at break point (%)	65.00	16.67	57.14	66.67	10.00	33.33
Gell time (s)	712	200	197	182	95	230

Table 4. Results of physico-mechanical tests on polyol substitution with sunflower oil

	S_0	S_a	S_b	S_c	S_d
Density (kg/m^3)	21.12	32.11	24.78	31.02	35.61
Rise time (s)	60	64	67	86	93
Compression set (%)	5.30	5.11	4.92	4.60	4.51
Elongation at break point (%)	65.00	50.09	66.51	16.67	47.06
Gell time (s)	712	640	548	531	527

In fig. 2 and fig. 6, the elongation at break point was presented as a percentage increase in length of the various samples when stretched before deformation. In fig. 2, the elongation at break point decreased from S_0 to S_1 and then increases up to S_3. S_3 is noted to have the highest value. This implies that S_3 have a better elastic property when compared with other samples.

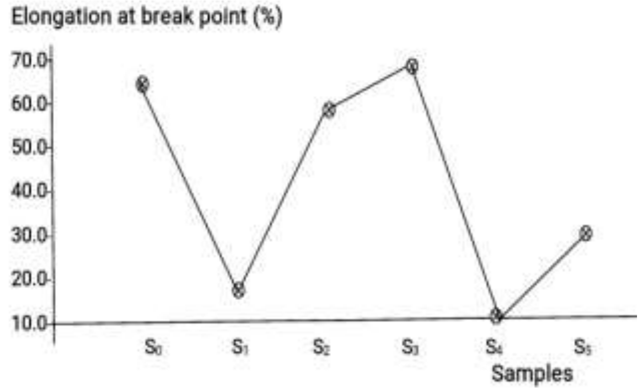

Fig. 2. Elongation at break point for silicone oil substitution with soybean oil

In addition, from fig. 3, there is a close range of density observed in S_0, S_1, and S_3. However, S_2 have an unusual high density. This increase in density could be as result of the closeness and tighteness of the interpenetrating polymer network in S_2 [5,20].

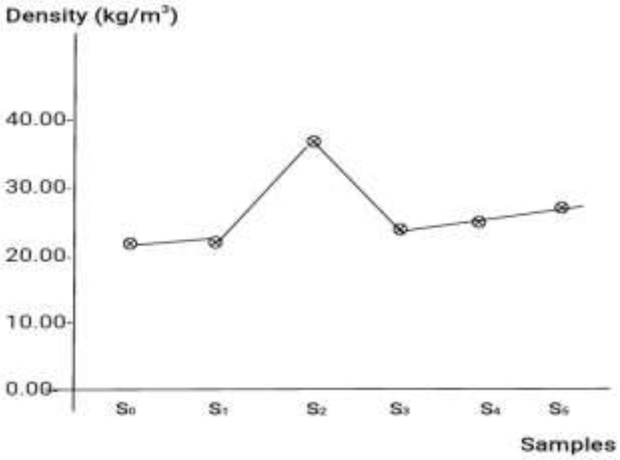

Fig. 3. Density for silicone oil substitution with soybean oil

In fig. 4, there is a gradual decrease in compression set up to S_3, after which there is a sharp increase. S_3 is known to have the lowest value. This implies that S_3 could not regain 3.01% of its original length, and is a positive development when compared with S_0 which could not regain 5.30% of its original length.

Results of polyol substitution with sunflower oil

Unlike in the case of soybean oil, in fig. 5, there is a continuous increase in rise time as the percentage of sunflower oil increase from S_0 to S_e. This signifies that the gas production reaction decreased progressively. However, the rise time of S_0, S_a and S_b are very close but there is a sharp increase in S_c. This infers that the substitution of polyol with sunflower oil can greatly affect the blowing reaction between TDI and water after the 10% substitution.

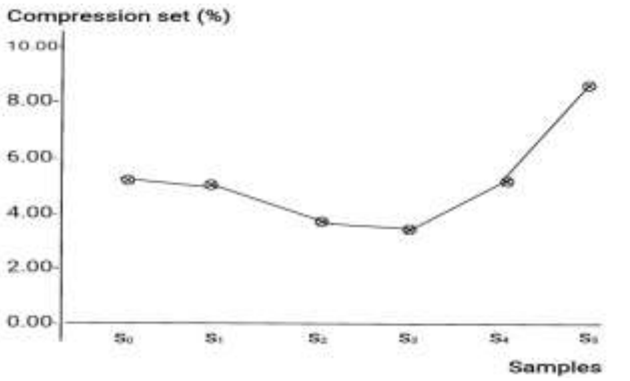

Fig. 4. Compression set for silicone oil substitution

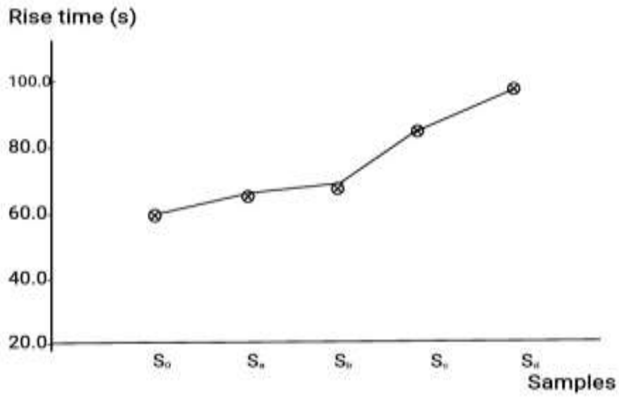

Fig. 5. Rise time for polyol substitution with sunflower oil

In table 4, there is a decrease in gell time from S_0 to S_d. The decrease in gell time signifies a decrease in demoulding time.

More so, from fig. 6, S_b have the highest value for elongation at break point. This implies that it will resist deformation better than the control sample (S_0).

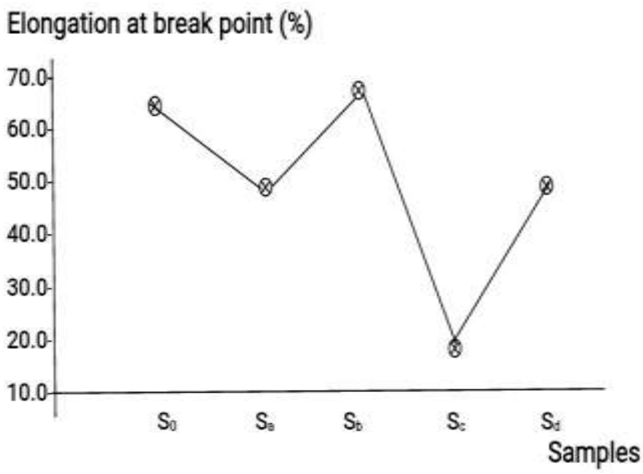

Fig. 6. Elongation at break point for polyol substitution with sunflower oil

In fig. 7, only S_b have a density closest to the control sample. The unusual high devaition in density of the other samples shows that only the substitution of 10% polyol with sunflower oil is closest to So.

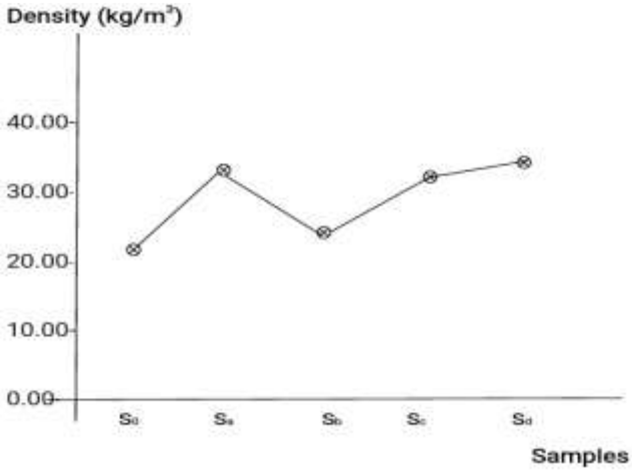

Fig. 7. Density for polyol substitution with sunflower oil

Furthermore, in fig. 8, there is a gradual decrease in compression set from S_0 to S_d. This infers that as the sunflower oil percentage increased, the foam was able to regain more of its original length after compression.

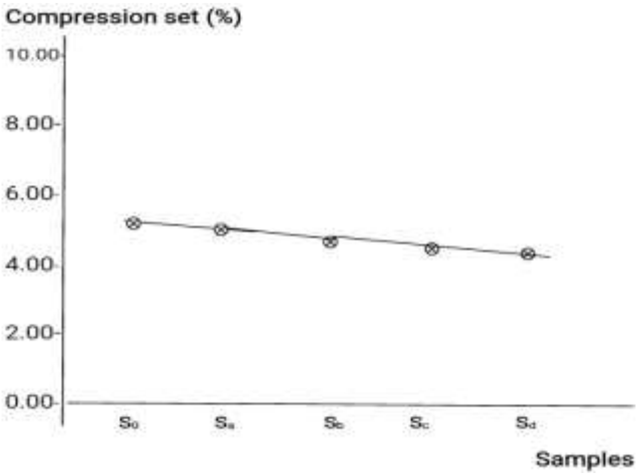

Fig. 8. Compression set for polyol substitution with sunflower oil

Conclusions

The substitution of 15% silicone oil with soybean oil and 10% polyol with sunflower oil have proven to show promising characteristics in the foam produced from this research. This is a huge plus to local foam manufacturers as this will help to reduce the over dependence of petroleum based polyol and subsequently drop the cost of production while maximizing profits. Also, Nigeria is blessed with a climatic condition that favours the cultivation of these vegetable seeds in large quantities, hence, this will certainly help to increase commercial farming of these oil seeds while incorporating the local content policy into our flexible polyurethane foam industries. However, there is still a need for more research on renewable vegetable oil and vegetable oil-polyol blend which would subsequently lead to the use of polyols and other additives gotten from renewable vegetable oil only.

Conflicts of interest

The authors declare no conflict of interest.

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