The Use of Castor Oil as a Reactive Monomer in Synthesis of Flexible Polyurethane Foam

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***Abstract*– The use of castor oil as a reactive monomer has been studied in order to evaluate the use in synthesis of flexible polyurethane foam in this work. The study indicated that castor oil can be blended up to 25% with polyether polyol in the flexible polyurethane foam formulation. It was established that the products of this formulation can be used for all flexible foam applications while 30% blend of castor oil with polyether polyol showed a wide variations from the National standard recommended values with respect to density, porosity, and compression and elongation tests. The cost benefit analysis conducted on samples of flexible polyurethane foam produced showed a significant decrease (about 10%) in the cost of production when compared with foam produced with 100% polyol.**

***Keywords*–** Castor Oil, Polyurethane, Polyether Polyol and Flexible Foam

I. INTRODUCTION

Improving the quality and cost effectiveness of polyurethane foam demands a constant search for new and renewable active monomer in the foam production. The use of non-conventional chemicals like castor oil as monomer in the production of polyurethane foam is been proposed. Foam manufacture is a combination of Science and Technology which is an integral part of everyday life. The commercial products known as polyurethane are complex polymeric materials usually formed by the reaction of liquid isocyanate component. The greatest advantage offered by polyurethane foam is their versatility in applications.

By proper choice of isocyanate and polyol, products can be made with properties ranging from downy softness of very low density flexible foam to the high strength of elastomeric bubble free castings [1]. Polyurethane chemistry is based on the reactions of isocyanates with active s. Isocyanates are compounds having one or more of the highly reactive isocyanate group (-N= C= O). This group will readily react with hydrogen atoms that are attached to atoms more electronegative than carbon [2]. Flexible polyurethane can be broadly divided into two groups, via; polyester and polyether foam. Polyester foams are produced using polymeric polyol containing ester groups in the molecular chain or inside chains while polyether foams are produced using polymeric polyol containing ether linkages (carbon-oxygen-carbon links) in the main molecular chain or inside chains. The more widely used polyether polyol have a relatively low molecular weight in the range of 500 to 3000 and are manufactured from propylene oxide and ethylene oxide [3]. The first foams were based primarily on the reaction of an aromatic isocyanate with a polyester polyol.

However, these foams proved unable to withstand many in-use temperature and humidity conditions and often failed by crumbling away [3]. Better performance was obtained with foams based on polyether polyols. Poly ether foam is more recently developed and is known to have many advantages over polyester foam which includes; good elasticity, one shot production eliminating pre-mixing, less expensive in production and wider applications compared to polyester foam [4]. It is therefore imperative to find a suitable raw material (substitute) that can be used for the production of polyurethane foam in place of polyol or as interpenetrating polymer networks (IPNs) to cushion the high cost of importing polyol in the country which serves as the main raw materials in polyurethane foam production. The production of polymers from renewable sources such as vegetable oil-based materials is currently receiving attention because of the economic and environmental issues [4].

Castor oil, a renewable material is known to have some properties in common with polyether polyol and this therefore necessitated this research in search for replacement or blending polyether polyol with locally sourced castor seed oil. In this work production of flexible polyurethane foams using locally sourced castor oil in place of imported polyether polyol blend in different ratio, physico-mechanical and various mechanical tests analysis on the samples of flexible polyurethane foams produced were undertaken and compared with the polyurethane foam produced from 100% polyether polyol.

II. MATERIALS AND METHODS

Castor seeds were obtained from Otukpo, Benue State, Nigeria. The oil was extracted through solvent extraction with hexane as the solvent at temperature of 60^{o}C to 80^{o}C in a soxhlet extractor using the method of [5]. Toluene diisocyante polyol(Voranate T-80TDI), polyol (Voranol 3322), Stannous octoate (Cosmo 29), dimethyl ethyl amine, DMEA (NIAX), silicone oil (TEGOSTAB 8110) and methylene chloride were gotten from Vitafoam Nig. Plc, Jos and Chellarams Chemicals Plc, Lagos, Nigeria. Physical properties of castor oil and physico-mechanical characterization carried out on the polyurethane foam produced include; density, compression

test, tensile strength and elongation at break, heat elongation at break, aging tensile strength, and hardness test (IFD), sag factor test, and porosity using the standard test method (ASTM D).

Table 1: Properties of Castor Oil

Property	Cold Processed	Solvent Extraction
Specific gravity at 25°C	0.961– 0.963	0.957– 0.963
Appearance	Clear	Clear
Refractive Index at 25°C	1.4764	1.475
Colour	Yellow	Yellow
Acid Value	2 - 3	3
Hydroxyl Value	160 – 164	160 – 164
Iodine Value	82 – 88	81 – 90
Saponification Value	179 – 185	176 – 187
Solubility in Alcohol	Complete	Complete

Source: [5], [7]

III. EXPERIMENTAL PROCEDURE

The 21 kg/m^3 density was chosen for the polyurethane foam produced based on market survey and corresponding formulation was determined in parts per hundred of polyol (pphp) accordingly. The formulation was translated into the actual weight of required chemicals. Castor oil at 21°C, polyol (21°C) and TDI were weighed in separate containers. Water, amine, and silicone oil were also weighed separately using syringe. This was poured into the castor oil/polyol container and it was stirred well. Stannous octoate was then added and stirred for 10seconds after which TDI was added and mixed rapidly for 6 – 8 seconds. TDI was added to the mixture. This mixture was then poured gently into the prepared mould. The cream and rise time were recorded using stop watch. The foam was removed from the mould for visual and touch inspections. The foam samples were aerated for 18hours before characterization so as to ensure complete curing. Stirrers and containers were cleaned using methylene chloride solvent. To harden the foam produced a TDI of known amount must be added [3]. A TDI index of 107 was used to calculate the amount of TDI needed in part per weight of polyol/castor oil based on the calculation from the formulation. The hydroxyl value of polyol and castor oil was calculated as follows:

Hydroxyl value= (part by weight of polyol × hydroxyl number of polyol) + (part by weight of castor oil × hydroxyl number of castor oil). Amount of TDI was calculated as follows;

Amount required to react with water (A) = part of water × 9.67 (conversion factor)

Amount required for Curing (B) = Hydroxyl number of polyol-castor Oil × 0.155 (conversion factor). Exact theoretical amount of TDI needed = A +B.

$$\text{The TDI needed} = \frac{\text{Index}}{100} \times (A+B)$$

Cost of Foam Calculation

In foam calculations, it is assumed that all of the water totally reacts to yield carbon dioxide gas. This gas causes the foam to rise to the analyzed density and is then totally lost.

The calculation of weight loss due to water is:

$$\text{Gasloss} = \text{Wt.of } H_2O \times \frac{\text{Molecular Wt.of } CO_2}{\text{Molecular Wt of } H_2O}$$

$$= \text{wt. of water} \times \frac{44}{18}$$

$$= 0.018 * 2.44 = 0.04392\text{kg}$$

Dry weight of foam = Wet weight of foam – Gas loss.

$$\text{Cost of foam} = \frac{\text{Total cost of raw materials}}{\text{Dry weight of foam}}$$

Table 2: Formulation of Polyurethane Foam Produced

Materials	Pphp	S_0 (g)	S_1(g)	S_2(g)	S_3(g)	S_4(g)	S_5(g)	S_6(g)
		0% castor oil	5% castor oil	10% castor oil	15% castor oil	20% castor oil	25% castor oil	30% castor oil
Polyol	100	400	380	360	340	320	300	280
Castor oil		0	20	40	60	80	100	120
OH value		42	48.1	54.2	60.3	66.4	72.5	78.6
TDI (index= 107)	53	212.3	216.1	219.8	223.6	227.4	231.2	235.0
Silicone	0.9	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Amine	0.2	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Tin catalyst	0.15	0.6	0.6	0.6	0.6	0.6	0.6	0.6
water	4.5	18	18	18	18	18	18	18

*Pphp= parts per hundred of Polyol-Castor Oil

IV. RESULTS AND DISCUSSION

Table 3: Summary of Physico-Mechanical Characterization of Pollyurethane Foam Produced

		Test methods	S_0	S_1	S_2	S_3	S_4	S_5	S_6
Density(kg/m^3)		ASTM D 3574, NIS 295: 1993	21.06	21.07	21.10	21.08	21.07	21.12	22.21
Compression set (%) 10% max		ASTM D 3574	7.14	7.22	8.13	7.89	8.22	8.76	14.65
Elongation at break (%)		ASTM D 3574 NIS 295: 1993 (120% Min)	134.98	135.42	129.56	125.78	126.67	125.38	110.43
Heat elongation at break (%)		NIS 295: 1993 (130% Min) ASTM D 3574	137.34	137.66	133.56	131.36	132.56	130.45	112.34
Tensile strength (KN/m^2)		ASTM D3574 (98 Min)	104.17	105.55	105.87	106.25	106.06	105.98	122.6
Porosity		ASTM D3574 (40min and 80 max)	70	67	65	62	60	57	37
Ageing Tensile strength(KN/m^2)		ASTM D3574	105.34	107.23	107.23	107.43	107.39	107.44	132.33
Indentation force deflection (IFD)(N)	75/25	ASTM D 3574	113.00	113.00	111.00	113.00	114.00	114.00	133.00
	60/40	ASTM D3574, NIS 295:1993	128.00	129.00	133.00	143.00	147.00	146.00	154.00
	35/65	ASTM D 3574	291.00	294.00	263.00	273.00	302.00	302.00	372.00
Support factor (65/25)		ASTMD3574	2.58	2.60	2.39	2.42	2.65	2.65	2.80
Rise time (secs)		NIS 295:1993	88	93	98	101	106	110	132
Cream Time (secs)		NIS 295:1993	13	14	17	19	20	23	29

Effect of Process Parameters on Polyurethane Foam Produced from Castor oil/Polyol

The desired densities were achieved for samples S_o, S_1, S_2, S_3, S_4, and S_5 but a wide variation was noticed in sample 6 as shown in the Fig. 1. This can be explained as a result of the closeness and tightness of the interpenetrating polymer networks in S_6.

Fig. 2 showed a corresponding increased in hardness with increased in castor oil for all the foam samples. This implied that the higher load bearing capacity can be achieved with increased castor oil ratio in the foam production.

It was revealed from fig.3 that all foam samples produced with the blended castor oil compared favourably with the set standard of ≤10% (NIS 295:1993) for compression tests of polyurethane foams except that of sample 6 which differs. This can be explained as result of tight closed cells in sample 6.

The elongation at break point decreased as the proportion of castor oil blended is increased which indicates that foam produced with high load of castor oil will exhibit very poor tear strength as depicted in fig.4. S_1, S_2, and S_3 compared very well with the 100% polyol in terms of their elongation at break.

Foam samples produced with 25% castor oil blended with polyol showed a good result when compared with foam produced with 100% polyether polyol except sample 6 where high tensile force is required to stretch the polyurethane foam to breaking point this can be explianed as result of the two functional groups (double bond and the hydroxyl group) present in castor oil which played a mojor role in the synthesis of the polyurethane foam as the proportions of it is increased in the formulation [6] as shown in Fig. 5.

It can be seen in Fig. 6 that the support factor for all samples of the polyurethane foams produced with the castor oil blend of polyether polyol fell within the set standard range of (2.4 – 3.0) (ASTM D 33574).

This revealed that the polyurethane foam produced from the blend of polyether polyol has the ability to provide support.

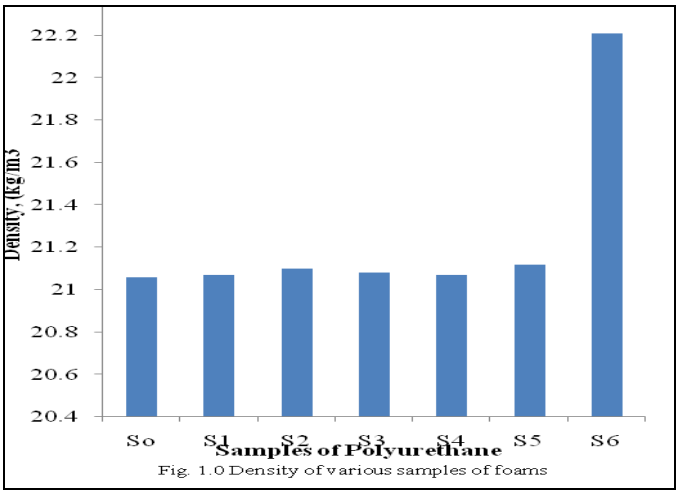

Fig. 1.0 Density of various samples of foams

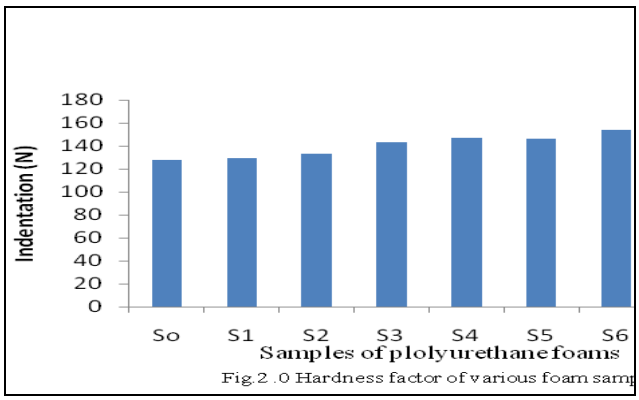

Fig.2 .0 Hardness factor of various foam samp

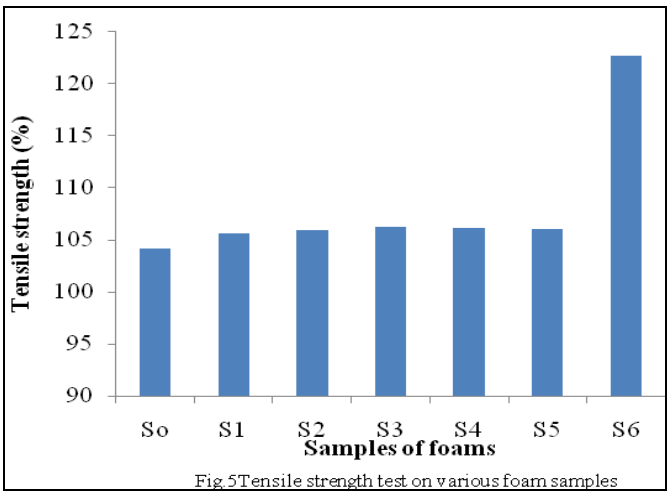

Fig.5Tensile strength test on various foam samples

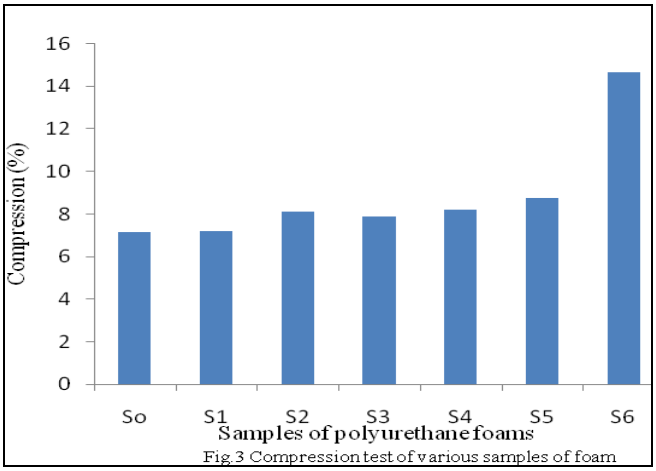

Fig.3 Compression test of various samples of foam

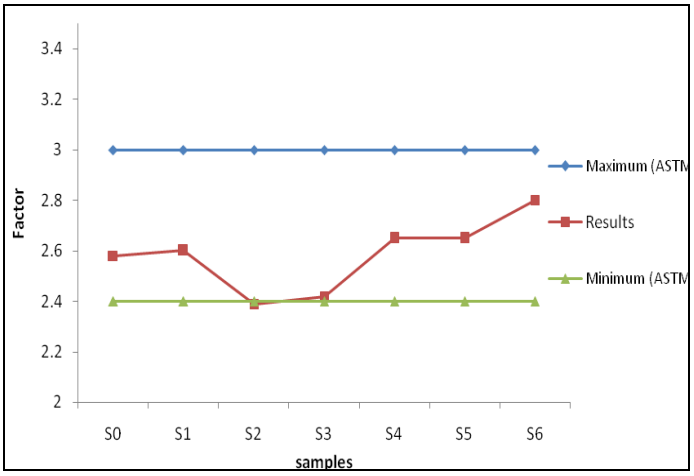

Fig. 6: Support Factor for various foam samples

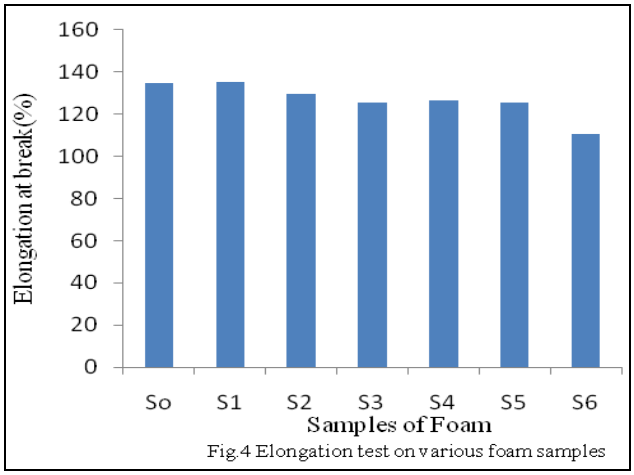

Fig.4 Elongation test on various foam samples

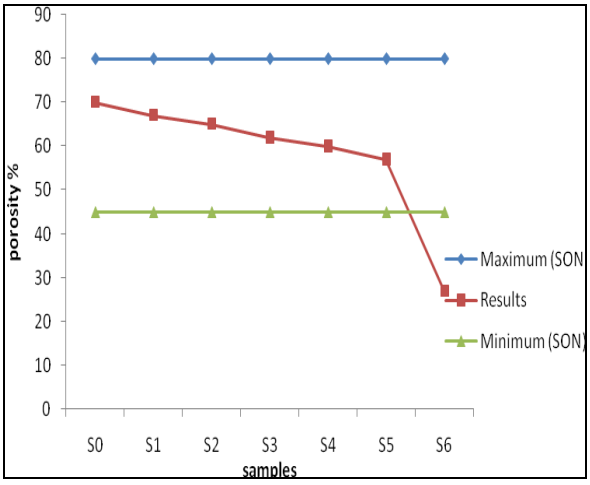

Fig. 7: Porosity of various foam samples

All the flexible polyurethane foam samples produced has their porosity values lie between the Standard Organization of Nigeria set porosity standard limit of 45%≤Porosity≤80% for all polyurethane foam except sample 6. This showed that all the foam samples produced has open cells. The dead cells characteristics of sample 6 makes it porosity value to fall below the set porosity standard. It can be seen also that as the proportion of castor oil is increased the porosity value decreased as well due to the functional group present in castor oil.

Table 4: Cost Summary of Various Samples of Polyurethane Foam Produced

SAMPLE	PRICE/KG ($)
S_0	3.22
S_1	3.17
S_2	3.12
S_3	3.07
S_4	3.02
S_5	2.96
S_6	2.91

Table 4 showed the summarized price of each samples of polyurethane foam produced per kilogram of foam samples. It is evident from the table that the price decreased as the proportions of castor oil/polyether polyol in the polyurethane foam is increased. It showed a 10% decreased in cost compared to 100% polyol flexible polyurethane foam.

V. CONCLUSION

The use of castor oil as a reactive monomer in the synthesis of polyurethane foams was investigated and the synthesis potential was confirmed. The study indicated that castor oil can be blended up to 25% with polyether polyol in the flexible polyurethane foam synthesis.

It was established that the products of this formulation can be used for all flexible foam applications while at 30% blend of castor oil showed a wide variations from the National standard values with respect to density, porosity, and compression and elongation tests. The cost analysis showed that the use of castor oil /polyether polyol in polyurethane foam production is cost effective commercially. The 25% blend of castor oil with polyether polyol gave the best results for all the tests carried out compared to other formulations.

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