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Research Article

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Sucrose as Renewable Source in Polyurethane Synthesis for Production of Lightweight Concrete

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Abstract The aim of this work to improve a new production of lightweight concrete by use the polyurethane foam as fine aggregates which has low density that decreased the density of concrete, so the concrete would be a lightweight .Sucrose was used as a natural source of cheap alternative to one of the components of the reaction as polyol with toluenediisocyanate. After polyurethane prepared, it converting into small parts as fine aggregates (sand), then mixed with other concrete contents water, cement and sand by different percentages forms and weight. The mixture is casting in certain cubic molds and undergo several trials to study its engineering properties through some major tests of concrete to obtain suitable results that allow it to be used in special structures that require lightweight concrete such as partitions, roofing, surface, etc..One of more important advantage of polyurethane, for thermal insulation which has a positive impact on energy conservation and thus achieving great economic feasibility. Synthetic polyurethane prepared examined by infrared IR and HNMR spectroscopy, which indicated polyurethane through the main groups of its composition. Thermal analyzes were also used to identify the thermal stability of the resulting polyurethane.

Keywords polyurethane, isocyanate, polyol, lightweight concrete

Introduction

Lightweight concrete can be considered as a type of concrete that contains a propellant by increasing the volume of the mixtures and providing addition properties like its own weight reduction [1]. It is less than ordinary concrete with dry densities of 300 kg/m3 - 1840 kg/m3; 87 - 23% less LWC is characterized mainly by its low density and thermally conductive. Its advantage is the reduction the dead load, the fast construction rate during constructions and low transport and handle cost. It turns out that the lightweight construction materials in concretes constructions can be used with economic advantages [2].

There are several advantages [3] to use lightweight concrete such as: fast constructed, Easy transfer, weight decreasing Significant, thermal insulation, Increase productivity.

Thermal insulation [4] is an important characteristic of lightweight concrete. Low thermal conductivity of lightweight concrete reduces the temperature rise of the embedded steel in the case of fire.

PU [5] is a kind of polymer which created of condensation polymer in which a diisocyanate (whose molecules contain two -NCO groups) and an alcohol with (two -OH groups) inter this kind of polymerization and formed. The polymers components are linked by urethane group (-O-CO-NH-). The -NH part of this group may react in a manner like to -OH group and form interlink between polymer series. Some industrials, depending on the class, both soft and hard PU foams are used. The production of many PUs related the exothermic behavior of the reaction of this polymerization. Liquids of low boiling point known a blowing agent may add to its monomers during polymerization process. Enough heat was released to make the liquid to a boil. Because of the boiling liquid formed, bubbles which form foam. In last time, the commonly substances used as low boiling liquids were chlorofluorocarbons.

Polyurethane as Fine aggregate

Recycled materials can be using to produce concrete. In this research we used crushed polyurethanes as fine aggregate of untreated or treated with cement syrups. We noticed that, the strengths of crushed polyurethane concrete are 65-75% of the normal concrete at 28 days. The polyurethane waste can be used for making lightweight. Normal samples of concrete using normal aggregate are tested to compare their results with LWC made from construction waste.

Because of wide application of Polyurethane foam, a large amount of polyurethane wastes are produced. Polyurethane foam has properties like sound insulation, high thermal conductivity, and lightweight. Based on these properties, polyurethane can be used into concrete as a partial replacement for coarse and fine aggregates, which considered as environmental friendly method for polyurethane foam. This research explains the important effect of polyurethane foam on concrete such as compressive strength, thermal conductivity, density which is compared with normal concrete.

We search to find some alternate material for aggregates. Polyurethane foam is one of the larger polymer product groups within the plastic family which wastes from end of life things like vehicles, scrapped refrigerator, district heating tubes and many other sources are receiving and its treatment and disposal. This material is having many properties like sound insulation, high thermal conductivity, and lightweight therefore we can use theirs in construction which will add new material for construction and add new method of its disposal which is environmental friendly. This research aims to use Polyurethane Foam in concrete and study its properties such as strength with its comparative study of strength against normal concrete. In this study 0.025 – 0.1 of Fine aggregate are replaced by polyurethane foam.

This research introduced the results of an experimental study of polyurethane foam which prepared into cementations mixture to produce LWC. Thermal conductivity observed is 0.56 to 0.24 m K for polyurethane as fine aggregates respectively.

In this research, we proved that PU Foam waste is possible to use in concrete for making LWC. Mechanical properties and durability was examined in this study of LWC in presence of PU foam waste which found as coarse and fine aggregates. The compressive strength achieved by use of PU Foam waste is between 12.7 – 20.5 Mpa for fine aggregates respectively.

Experimental

Materials

Toluene diisocyanate (TDI) purchased from Romail, starch purchased from Fluka. All other solvents and reagents were of analytical grade.

Instrumentation

Melting point was measured using Thermal Microscope (Kofler-method), and Reichert thermovar, Stuart SMP 30. Infrared spectrophotometer measurements were performed using Shimadzu FT-IR 8400 series

Fourier Transform, 1H-NMR spectra were measured with a bruker spectrophotometer model ultra-shield at 300.13 MHz in DMSO-d6.

Polyurethane synthesis

A-Preparation of soft flexible polyurethane foam (S –PU) from (TDI) and (SUCROSE)

(34.2gm) of SUCROSE was added in a disposable cup, (5 ml) of DMF were added to the cup of SUCROSE and mixed well. 17.5 amount of TDI was added to the mixture, the solution contents were mixed together using stirrer rod. After 20s of stirring, the cup became warm, refers to an exothermic reaction. The expand foam poured into a big pan, then it begun hardened completely as a big block foam of polyurethane, figure 1. It was expanded to about 30 times more than its original volume, the mixture was interred in condensation polymerization and the product foam was soft flexible.

B- The big block of low density soft flexible polyurethane had been crushed into a large pieces according to the size of the sand as showed in figure 2. This type undergoes sieve analysis according to the specifications of the center National construction Laboratories to obtain the highest mechanical overlap between its parts. The crushed polyurethane mixed with cement, water and sand by different ratios with sand weight. After the mechanical mixing of the previous components, the cement mixture was poured into cubes measuring (100 * 100 * 100 mm) figure (3) and then covered with a nylon sheet to keep it dry. After 24 hours, the cubes were opened and fed into the water basin for the purpose of maturation of the cement reactions (7, 28 days) to be followed by the required tests.

Figure 1: Bulk piece of hard polyurethane

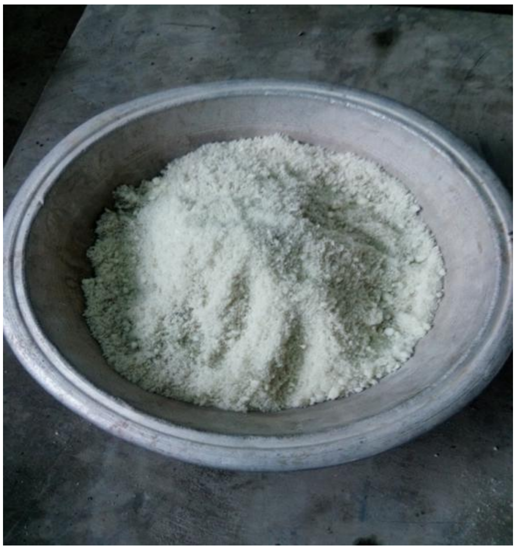


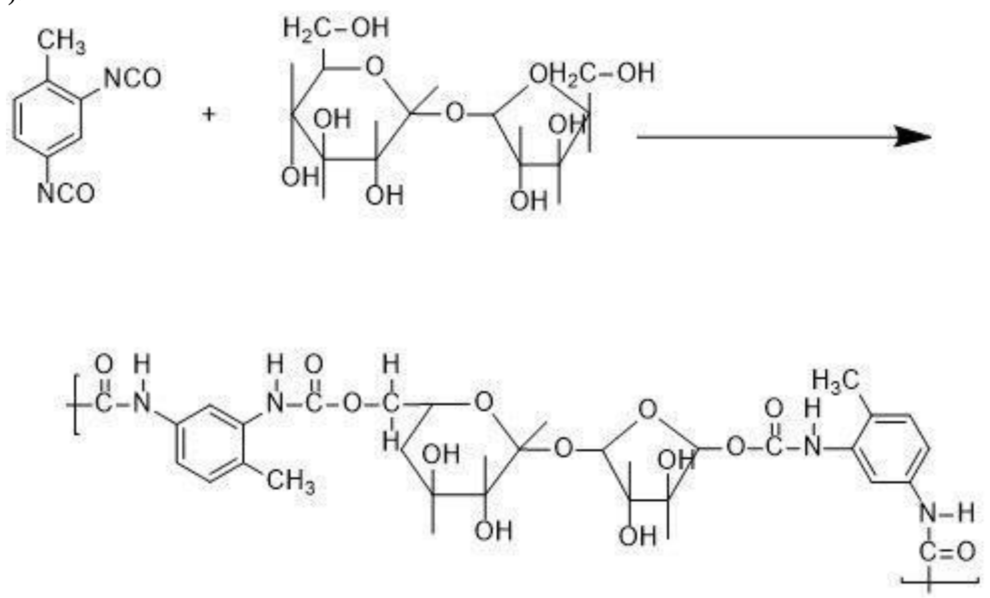
Figure 2: Polyurethane crushed as fine aggregates

Figure 3: Concrete cub samples

Result and Discussion

Preparation of PU(S-PU) from (TDI +SUCROSE)

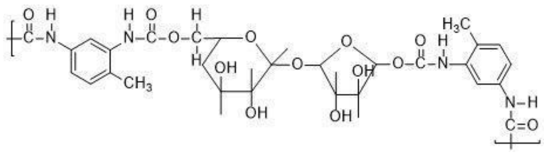
Sucrose used in this method as renewable raw material for green synthesis chemistry polyol components for synthesis of PU foam. It was changed firstly into the mixture in presence of suitable solvent (DMF) as cream. In this method PU result from the reaction of (**SUCROSE**) as polyol and (TDI) as isocyanate. This process started by direct added of a polyol and diisocyanate in One-step polymerization. Thermally, this reaction considered as exothermic, it temperature increased above 80-100 °C during PU preparation. PU reaction performed is given in Scheme (1).



Scheme 1: PU synthesis(S-PU) from (TDI + SUCROSE)

Following the physical properties of product polyurethane:

Table 1: Physical properties of polyurethane prepared

Type	Polyurethane	Colour	Soften Point	Conversion Ratio
S-PU		white	260-268	98%

Essential states of PU conversions

PU passed through its formation three states: Cream, gel and rise. These states differ in rate depending on their formation and the type of PU. Table (2) show the time of formulation obtained for each state.

Table 2: PU states conversion values

Batch No.	Cream time	Gel time	Rise time	Total time
1	3	6	11	20

In this batch, cream, gel and rise times [6] were 3 s 6 s and 11 s respectively. The total time is 20s, that mean it's a short time to form the polyurethane polymer.

Crushed PU as fine Aggregate in Concrete

In fine aggregates replacement, the results of the tests were obtained from samples of concrete cubes with crushed PU and without crushed PU. These results are reported on average of three samples at aged (28) days and satisfy BS: 1881: part 3: 1970, 1881: part 4: 1970 and IRQ.S. 52/1970 requirements. We found that using of crushed PU in concrete caused decreasing of compressive strength [7] during allowed range. From physical and mechanical results, the structural case of concrete doesn't allow using this type of concrete for constructions of high strength, but it could be used in the cases of lower strength like partitions or the same used. When the ratio of crushed PU to coarse aggregate increases, the water / cement ratio is increased that which cause the strength of concrete. We achieve a fact that PU foam after the end of its life cycle could use in industrial of concrete [8]. So it is a case of replacement of PU concrete and foam light concrete.

Concrete tests by used PU As fine Aggregate:

Following the results of PU replacement for fine aggregates:

1. Density

Table (3-6) results of concrete tests when PU used as fine AGG.

PU / Sand (w/w)	Density (kg/ m^3)
Reference	1999
0.025	1805
0.05	1770
0.075	1665
0.1	1605

2. Compressive Strength

PU / Sand (w/w)	Compressive Strength (Mpa)
Reference	21.7
0.025	20.5
0.05	19.0
0.075	15.1
0.1	12.7

3. Thermal Conductivity

PU / Sand (w/w)	Thermal Conductivity (W/Mk)
Reference	0.8002
0.025	0.5593
0.05	0.4770
0.075	0.3084
0.1	0.2446

4. Absorptivity

PU / Sand (w/w)	Absorptivity %
Reference	1.9
0.025	1.2
0.05	2.7
0.075	3.5
0.1	5.2

Results above have shown that LWC has the obtained strength to be alternative materials for building industrialized construction systems. The strength of the concrete with the light foam is low for a mixture of lower density. This returned to increased voids throughout the sample which caused by the foam. So, that decreases the compressive strength of PU-concrete. Expanded lightweight concrete is suitable for use as a non-load bearing wall as it has a lower compressive strength than recommended. The structure of polymeric foams is divided into two types, open cell and closed cell foams, but most also contain a small amount of the other. The production of foams can occur in different ways.

In other hand polymeric foams have best thermal insulation properties and can also be regular to have different mechanical strength and moisture absorption [9].

Polymeric foams have widely uses in all types of application because they can be made from many types of polymers and there are many blowing agents to adjust the foam to get specific properties. Polymeric foams can be rigid or flexible by modifying the chemical composition, density, structure and as raw materials used.

Generally, the following points explain the effects of PU used as concrete aggregates. Replacement on product of LWC:

- This study has shown that crushed PU can be used as a fine aggregate in a suitable method for the manufacture of LWC with acceptable strength characteristics.
- The use of crushed PU as a fine aggregate decrease the compressive strength of concrete depending on the ratio of crushed PU used.
- The use of crushed PU as a fine aggregate in concrete increases the water / cement ratio, while increasing the absorption of concrete into the water.
- The workability of crushed PU concrete is lower than that of normal concrete

Discussion

This discussion is focused on the performance of LWC. The results presented in this chapter relate to the compressive strength, density, thermal conductivity and water absorption test of different test mixes of lightweight concrete replacement with PU as fine aggregates.

The purpose of the density and compressive strength [10] tests is to identify the performance of expanded lightweight concrete. We had been seen that the compressive strength of expanded light concrete is low for a lower density mixture gradually .That return to the increasing of voids throughout the sample caused by the product foam in the mixture which reduced the density. As a result, compressive strength will also decrease with voids increasing. The compressive strength required for LWC is 3.45 MPa as a minimum value at 28 days as a non-load bearing wall. We found it greater than 3.45 MPa, from these mixtures and it is therefore acceptable to produce a non-carrier structure.

Results of FTIR of flexible foam (S- PU)

FTIR spectra of the (**S-PU3**) sample which shows specific peaks that respect to the spectrum of the sample. Peak at 3475.84 cm^{-1} for an OH group. Peak of 3250.16 cm^{-1} of N-H group of urethane linkage. The other peak at 2931.90 cm^{-1} refers to alkanes with C-H stretching. Peak at 1649.19 cm^{-1} for C = 0 carbonyl group which consider as specific bond for urethane linkage. At 1649.19 cm^{-1}, there is a peak of aromatic ring with the bond of C=C based on the structure of TDI. The two peaks at 1521.89 and 1496.81 cm^{-1} give indication for aromatic nitro compounds with bond N-O as in TDI structure of cyanate group which attached to aromatic ring.

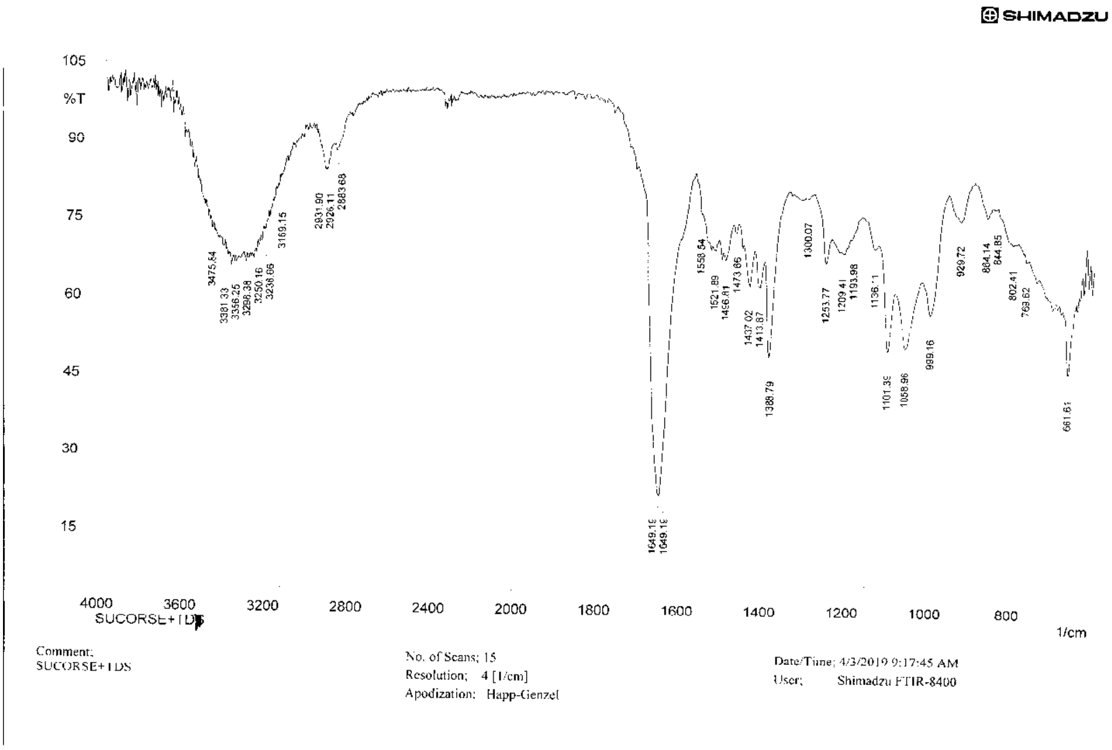


Figure 4: FTIR spectra of flexible foam (S-PU)

The ^{1}H-NMR spectrum of soft flexible PU foam (S- PU) shown in figure 6 showed the signal appointment in the identical formula, which showed the following signals:
2.12 ppm (S ,3H , CH3) for TDI , 3.40 , 3.73 ,3.97 ,4.27 , 5.02 , ppm , (S , 1H , CH), 4.08 ,4.21 , 4.34 ,4.46 , ppm (S, 2H , CH_2) , 3.58 ppm (S , 1H , OH) , 7.19 , 7.30 , 8.01 , 8.70 ppm (m, Ar-H ring) , 9.15 ppm (S , 1H , NH).

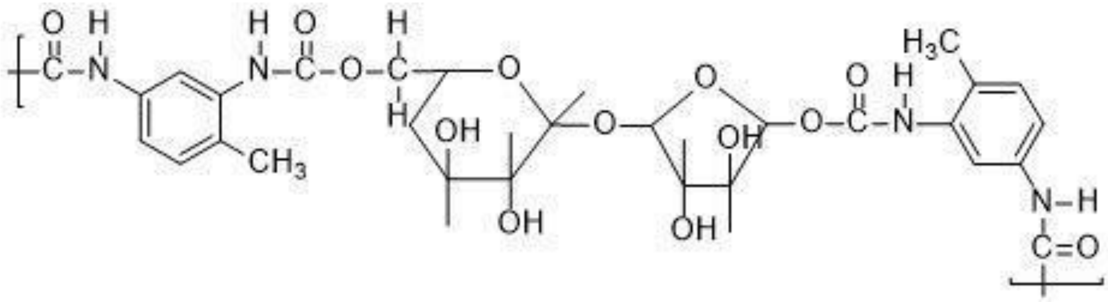


Figure 5: Chemical Structure of S- PU

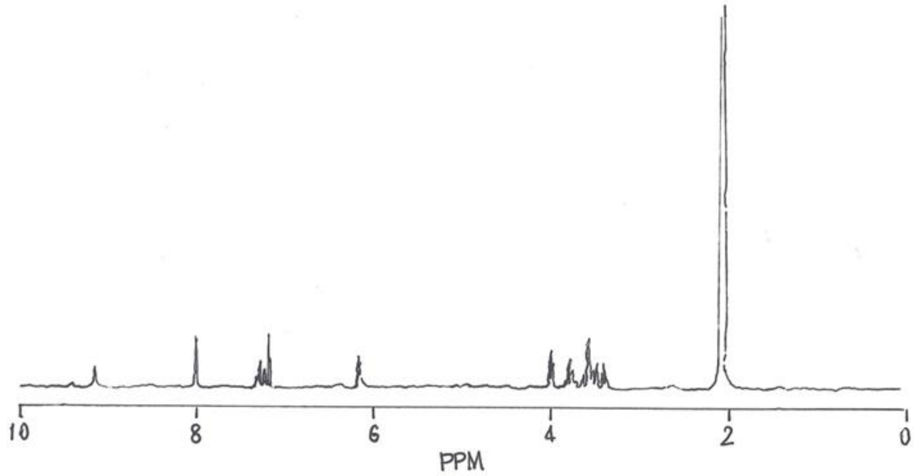


Figure 6: Chemical Structure of S- PU2

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