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Rigid polyurethane foam reinforced with some agricultural wastes

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A R T I C L E I N F O

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A B S T R A C T

The use of natural fiber bolster polyurethane composite foams is changing into more and more fashionable within the cellular foam industry. This demand is due to the increasing use of environmentally friendly, biodegradable and sustainable materials to manufacture polyurethane composites for such applications. In this regard, natural fibers from agricultural wastes are preferred over their synthetic counterparts because of their ready availability, light weight, biodegradability, strength and cost effectiveness. In addition to the renewable nature, the use of natural fibers in polyurethane foams leads to composite foams with better properties than pure polyurethane foams (PUFs). It was made by foaming a liquid mixture of isocyanato-polyols in presence of a blowing agent. This article contains an experimental study of improving the reinforcement of rigid polyurethane foams (RPUFs) by the means of incorporating various amounts of each cotton stalks (TS) and corn stalks (CS). Five different percent volume of reinforcement (5, 10, 15, 20 and 25) of cotton or corn stalks were used with (RPUFs), beside the control ratio of (0 %). The influence of incorporating (TS) and (CS) on rigid polyurethane foams (RPUFs) is reported. A produced composite which mad from "RPUFs" and "TS and CS" were prepared for testing to measure bulk density "Bd, kg/m^3", water absorption "Wa, %", compressive strength "P, MPa" and deformation "D, mm". The results showed that the previous physical and mechanical properties were affected by previous percent volume of reinforcement. It indicated that there were some improvements on some physical and mechanical properties of produced composite. There was a water absorption reduction ratio of 82.31 and 42.97 % at reinforcement ratio of 25 % for cotton and corn stalks respectively, in comparison with control (0%). Also, there was a compressive strength increasing ratio of 94.40 and 82.76 % at reinforcement ratio of 25 % for cotton and corn stalks respectively, in comparison with control (0%). Cotton stalks showed the best, lowest, water absorption values than corn stalks and it showed the best, highest, compressive strength value than corn stalks. The lowest value of water absorption was 51.79 % at reinforcement ratio of 25 % and the highest value of compressive strength was 0.89 MPa at reinforcement ratio of 25 % for cotton stalk.

1. Introduction

Agricultural plants are not inherently waste materials, but the great importance attached to the edible part of the plant overshadows the use of the remaining plant product. Here in Egypt, the plants are cultivated on a large scale. After harvest, the plants stalks are burned in many areas. Clean air regulations prohibit this combustion. The targeted use of plant stalks for making materials is increasingly feasible. In this context, it is worth noting that the use of agricultural waste

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as a source of biomass poses costly and challenging problems for crop producers. For example, cotton stalks (CS), the agricultural byproduct of cotton production that remains in the field after harvest (Mythili and Venkatachalam, 2013), is an abundant waste with a global estimate of 79.5 million tons per year in 2019–20 (Johnson et al., 2020).

Cotton is one of the main cash crops grown in Egypt, covering an area of around 375,000 fed., and producing 330,300 Mg of cotton seed. According to the (A.E.B., 2016), the yield and the amount of cotton waste were determined to be around 500,000 Mg/year. Corn stalks are agricultural by-products and currently have no economic value. The disposal of agricultural waste is currently a major economic and ecological problem. However, the abundance and availability of cornstalks as an agricultural by-product makes them a good source of raw materials for many purposes. Egypt produces 3.12 million tons of cornstalk by-products annually (Husseien et al., 2009). The growing demand for a clean environment has led to natural resources being used to develop innovative green materials (Sair et al., 2019). Polyurethane foams (PUF) are a particularly useful group of cellular polymers with many uses in various industries. They are widely used in consumer bedding and pillow products such as upholstery, furniture, car seats, insulation, and in applications where other materials are used due to the versatility of polyurethane chemistry (Gama et al., 2018). The PUFs are normally produced via a polyaddition reaction between polyols and isocyanate with other additives to enhance the foaming process (Kausar, 2018). There are two main types of PUF, Rigid Polyurethane Foam (RPUF) and Flexible Polyurethane Foam (FPUF), which differ in the type of raw materials and additives used in their manufacture. The raw materials for its manufacture come mainly from petrochemical sources, which are now unpopular due to environmental problems associated with the synthesis of these materials (Akindoyo et al., 2016; Czlonka et al., 2020). Polyurethane foams (PUFs) are versatile materials that are widely used in various fields such as medicine, automotive parts, and construction applications due to their low thermal conductivity and excellent mechanical properties (Asim et al., 2015; Wiyono et al., 2016). In recent years, the use of bioresources for the production of PUFs has gained considerable attention due to growing concerns about the substitution of petroleum-based products which can cause environmental problems. However, PUF productions from bio-resources are not yet suitable for commercial applications because they do not meet the requirements of the industrial standard (Akindoyo et al., 2016). Among the renewable raw materials that are used in the polyurethane industry today, the use of natural fibers as fillers has attracted a great deal of attention. It is well known that fillers improve the density and the mechanical, optical, electrical and thermal properties of polymers. In addition, they offer an inexpensive way to make polymer compounds without compromising their inherent properties (Wypych, 2016). Therefore, a further improvement in PUF properties has been widely developed. There have been several strategies to improve PUF properties. One of these strategies is the use of fillers or additives incorporated during the foaming process. The addition of fillers in the PUF process would ultimately improve the thermomechanical properties of the manufactured PUF for improved properties for specific industrial applications. Recently, the use of natural fibers in polymer composites has increased dramatically due to its low price compared to synthetic fibers (Javnil et al., 2002). Problems such as the need to improve the management of collection waste and the poor mechanical properties of polymers can be solved by producing natural polymer / fiber composites with reinforcing efficiency modulated by natural fibers of different origins (Azwa et al., 2013). The incorporation of these lignocellulosic fibers into the PUF formation process will increase the mechanical strength and improve the thermal stability of the manufactured PUF (Ozgur et al., 2017). The widely known source of lignocellulosic fibers is extracted from wood and bark (Chang et al., 2015), but the extraction of fibers from these sources is difficult to process due to its hardness. The mechanical characteristics of a polymer composite reinforced with natural fibers result mainly from the quantity and type of fibers, in addition to the interfacial resistance between the reinforcement and the matrix. An alternative for modulating the mechanical performance of the composite is to develop hybrid composites, a material produced by combining two or more types of reinforcement (Manteghi et al., 2017; Yusoff et al., 2016). Several studies suggest that adding natural fibers to polyurethane composite foams improves the mechanical properties of such composite foams. Bryskiewicz et al. (2016); Silva et al. (2008) studied the influence of Eucalyptus grandis fibers on rigid PUs and found that adding 16% (w / w) of natural fibers significantly increased their mechanical strength and thermal conductivity. Javni et al. (2003) reported that adding up to 20% (w / w) silica fibers increased both hardness and modulus of elasticity with only a small reduction in resilience. Since then, the modulus of elasticity of the hybrid composite has been related to the number of crosslinks between PU chains and hydroxyl groups exposed on the surface of the fiber. The use of polyurethane foam is far common today. Reinforced composites are used in applications where good mechanical and other properties are required, such as: Engineering and construction applications. The use of natural fibers can offer several advantages, for example the surface of the product, it has a natural look, a faster production cycle is possible, even savings on polymer and the like.

Natural fibers have good properties and are easy to obtain and manufacture (Jamrichova and Hejdukova, 2013).

The main objective of the present study was to prepare rigid polyurethane foam reinforced with local Egyptian agricultural residues. Also, to test reinforced rigid polyurethane foam with different proportions of agricultural residues in its matrix if they are used for improving some mechanical properties.

2. Materials and methods

The experiments of present work were carried out in summer of 2021 at faculty of agricultural engineering, Al-azhar univ., Cairo, Egypt.

2.1. Raw materials

Cotton and corn stalks (TS and CS) were collected from a field in Kafer El-shiekh Governorate, Egypt, and prepared for the experiments by cutting them into small pieces of 200 mm length for each. The mean values of its diameter were recorded to be 11 and 19 mm, respectively. They have been dried naturally before preparation by laying them outside during the intense hours of sunshine of the day. After drying, the moisture content on a wet basis was approximately ± 9.95% and ± 8.39%, respectively.

2.2. Raw materials preparation

Cotton stalks and corn stems were washed in boiling water at 100 °C for 1 hour and naturally dried in the sun for 8 hours, then mercerized by immersing in an aqueous solution of 1.5 % w/w sodium hydroxide (NaOH) and hydrogen peroxide 30.0% w/w at room temperature for 48 hours. Next, the cotton stalks and corn stems were washed with water to remove excess NaOH. Finally, the cotton stalks and corn stems were dried naturally in the sunshine for 6 hours and stored.

2.3. Rigid Polyurethane Foam

The materials used to make the rigid urethane foam were obtained from commercial sources. Rigid polyurethane foam (RPUF) has the following chemical properties: (A) Polyol component: a mixture of polyol, flame retardant, catalyst, stabilizer and HFC blowing agent (polyol: density = 1.13 g/cm^3 at 25 °C, viscosity = 396 mPa at 25 °C) (B) isocyanate component: contains a polymeric diphenylmethane-MDI (methylenediphenyl diisocyanate, IsoPMDI 92140) (density = 1.23 g/cm^3 at 25 °C,viscosity = 270 mPa at 25 °C).

2.4. Specimen's preparation mold

In this study, a rectangular plywood mold with inner dimensions of (300 × 200 × 50 mm) was used to mold specimens for the test. The plywood used to manufacture the mold was wooden residues received from a furniture workshop within side the El-Gharbia Governorate, Egypt. Mold made to be removed and installed by connecting the wooden sides with screws. Its top (300 x 50 mm) was opened to place the stalks or stems and pour the foam through. The underside facing the open side had many metal pins (1.0 mm) in diameter to help even out the placement of stalks or stems while pouring foam. After pouring the foam and allowing sufficient time to fully set, the mold was removed and the reinforced foam removed and then cut with a power saw into specimens of appropriate dimensions for testing.

2.5. Universal materials tester

In order to study some mechanical properties of produced specimens, a digital universal materials tester was used as in Fig 1; its operation is possible with or without a PC. The MT 2020 features a strong and rigid construction and clear layout for easy understanding of test performance. A large base provides stability and is equipped with 4 handles for easy movement, if required. The loading force is applied by means of a hydraulic system which is manually operated with a hand pump. Force is displayed on a digital display with 0-20kN range, with a drag pointer for maximum force. The deformation is displayed on a digital display 0-20mm/0.01mm. The specimen is easily connected by means of screw-type chucks. The whole system is mounted on a strong sheet-metal base with feet. The technical specifications of the tester are the following:

- Max. Applied force: 20 kN
- Max. Piston stroke: 54 mm
- Force transducer (optional): full bridge DSM
- Deformation transducer (optional):
- linear potentiometer 0-50mm
- Gauges: up to 20mm / 0.01
- Hydraulic oil: VG 46
- Interface (optional): USB
- Dimensions: ca. 500 x 350 x 705 mm
- Weight: ca. 48 kg

Fig. 1. Photograph of Universal materials tester.

2.6. Test procedures

Five reinforcement volumes of cotton and corn stalks (TS and CS) were replaced with rigid polyurethane foam (RPUF) to study water absorption "Wa, %", bulk density "Bd, kg/m^3", compressive strength "P, MPa", deformation "D, mm", deflection "d, mm" and applied load "F, N" of the produced composite, which was influenced by the following variable: percent volume of reinforcement "PVR, %". The experiments were conducted at the Research Center of the Faculty of Agricultural Engineering, Al- azhar University, Nasr City, Cairo, Egypt.

2.7. Percent volume of reinforcement "PVR, %"

The rigid polyurethane foam (RPUF) ratios by volume were added to five reinforcement ratios of each (TS) and (CS) by volume. The cotton and corn stalks ratios were 5, 10, 15, 20 and 25 (%) by volume, in addition that ratio of (0 %) was without adding (TS) and (CS) as a control specimen. Samples of 200 mm in length for each were taken from 100 (CS) and (TS), the average diameter of each of them was 19 and 11 mm, respectively. Depending on its average length and diameter, the volume of one sample was calculated for both (CS) and (TS), which the average volume of sample for each (CS) and (TS), were 56,677 and 18,997 cm^3, respectively. Five volumes of 5, 10, 15, 20 and 25% from the total mold volume used in the samples preparation were calculated. The volumes of 150,300,450, 600 and 750 cm^3 of (TS) or (CS) were required to achieve the reinforcement ratios of 5, 10, 15, 20 and 25% by volume, respectively. To achieve these previous reinforcement volumetric ratios, the total required number of stalks was calculated to be used with each volumetric ratio. And it turned out that, the required number of corn stalks were 3, 5, 8, 11 and 13, respectively. While, the required number of cotton stalks were 8, 16, 24, 32 and 40, respectively.

2.8. Preparations for testing

The plywood rectangular mold lined with aluminum foil was used to prepare test specimens. About 5, 10, 15, 20 and 25% of (TS or CS) by volume respectively, were arranged inside and placed vertically in the mold. Rigid polyurethane foam (RPUF) was produced between and around (TS and CS) by placing a 50-50 (A-Polyol and B-isocyanate components) by volume in the bottom of the mold immediately after mixing. After about 30 min, the composite of rigid polyurethane foam (RPUF) and (TS and CS) was removed from mold. The produced composite of rigid polyurethane foam (RPUF) and stalks were cut into 25 x 30 x 100 mm rectangular beams for mechanical measurements.

2.9. Experimental design

A combination of each of two types of cotton and corn stalks (TS and CS) and five ratios from them which to be added to rigid polyurethane foam resulting, in ten treatments. Each treatment was repeated three times to give three replicates, resulting in 30 specimens.

2.10. Measurements

The following measurements were carried out at ambient room temperature of 28 °C and relative humidity of 57 %. The following measurements were carried out for each specimen:

2.11. Water absorption percentage "Wa, %"

The initial weight "M_d" of each sample was recorded; each sample was immersed in fresh, clean tap water at (20 - 23°C) for periods of 60, 120, 180 and 240 min. Each sample was removed from the water at the end of each period and excess water removed, and then each sample was weighed and re-immersed for a further 60 minutes, the same weight readings recorded, and so on up to 240 minutes. The water absorption percentage "Wa, %" at the end of each time above was calculated according to the following equation:

$$\text{Water absorption "Wa"} = \frac{M_w - M_d}{M_d} \times 100 \qquad [1]$$

where:

M_w: Mass of wet sample (g).

M_d: Initial mass of sample (g).

2.12. Compressive strength "P, MPa"

The rectangular beams of 25 x 30 x 100 mm were tested with the stalks length parallel to the direction bending stress. The values of applied load "F, N", compressive strength "P, MPa", deformation "D, mm" and deflection "d, mm" were recorded automatically on the digital display; the data were analyzed after that according to the device conditions.

3. Results and discussions

3.1. Water absorption "Wa, %" via immersion time "IT, min"

Figs. 2 and 3 illustrate relation between immersion time "IT, min" and Water absorption "Wa, %" at different percent volume of reinforcements "PVR, %" for "TS and CS". It shows that water absorption percentage is affected by "IT, min". Water absorption percentage "Wa, %" increases by increasing "IT, min" from 60 to 240 min at percent volume of reinforcements "PVR, %" for each "TS and CS". The data showed that water absorption percentage "Wa, %" is increased from (228.24 - 292.82), (157.14 -193.11), (141.15 – 158.35), (102.22 – 116.93), (80.50 – 91.94) and (64.38 – 51.79) at "PVR, %" of 0, 5, 10, 15, 20 and 25 respectively, for (TS). The results showed that highest values of "Wa, %" were 292.82 and 193.11 at "PVR, %" 0 and 5 respectively, with reduction ratio of 34.05 %, and lowest value of "Wa, %" was 51.79 at "PVR, %" 25, with reduction ratio of 82.31 %, for (TS). On the other hand, the water absorption Wa,

%" is increased from (228.24 - 292.82), (217.13 -276.95), (212.18– 251.26), (181.70 – 232.33), (156.51 – 220.06) and (136.08 – 166.99) at "PVR, %" of 0, 5, 10, 15, 20 and 25 respectively, for (CS). The results showed that highest values of "Wa, %" were 292.82 and 276.95 at "PVR, %" 0 and 5 respectively, with reduction ratio of 5.42 %, and lowest value of "Wa, %" was 166.99 at "PVR, %" 25, with reduction ratio of 42.97 %, for (CS). From the previous results, it is clear that cotton stalks had lowest value of water absorption (better) than corn stalks, may be because porosity of cotton stalks are lower than corn stalks.

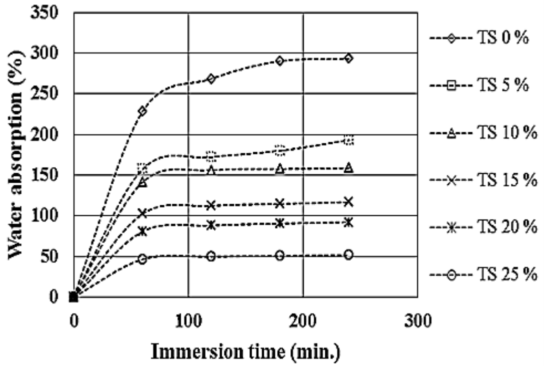

Fig. 2. Immersion time via water absorption percentage at different "PVR, %" for (TS).

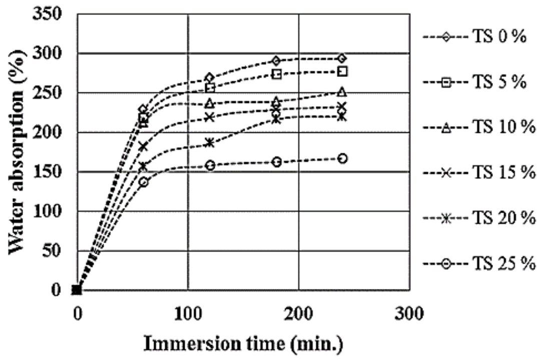

Fig. 3. Immersion time via water absorption percentage at different "PVR, %" for (CS).

3.2. *Compressive strength "P, MPa" via "PVR, %" and bulk density "Bd, kg/cm³"*

Figs. 4 and 5 show, the relation between percent volume of reinforcement "PVR, %", compressive strength "P, MPa" and bulk density "Bd, kg/m³" for "TS and CS". It illustrates that compressive strength "P, MPa" is affected by percent volume of reinforcement "PVR, %" and bulk density "Bd, kg/m³" for each "TS and CS". Compressive strength increases with increasing percent volume of reinforcement "PVR, %" and "Bd, kg/m³" for "TS and CS". The obtained data indicated that, the compressive strength is increased from 0.05 to 0.89 "P, MPa" with increasing bulk density "Bd, kg/m³" from 38.01 to 231.42 and percent volume of reinforcement "PVR, %" from 0 to 25. The results showed that lowest value of "P, MPa" was 0.05, and highest value was 0.89 with increasing ratio of 94.40 %. While, lowest value of bulk density "Bd, kg/m³" was 38.01, and highest value was 231.42 with increasing ratio of 83.58 % for cotton stalks. On the other side, the compressive strength is increased from 0.05 to 0.29 "P, MPa" with increasing bulk density "Bd, kg/m³" from 38.01 to 132.34 and percent volume of reinforcement "PVR, %" from 0 to 25. The results showed that lowest value of "P, MPa" was 0.05, and highest value was 0.29 with increasing ratio of 82.76 %. While, lowest value of bulk density "Bd, kg/m3" was 38.01, and highest value was 132.34 with increasing ratio of 71.28 % for corn stalks. From the previous results, it is clear that cotton stalks had highest values, better, of compressive strength and bulk density than corn stalks, may be because of the strong nature of cotton stalks structure than corn stalks.

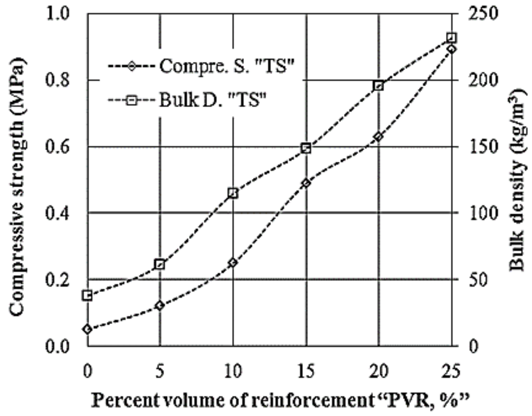

Fig. 4. Compressive strength versus bulk density at "PVR, %" for (TS).

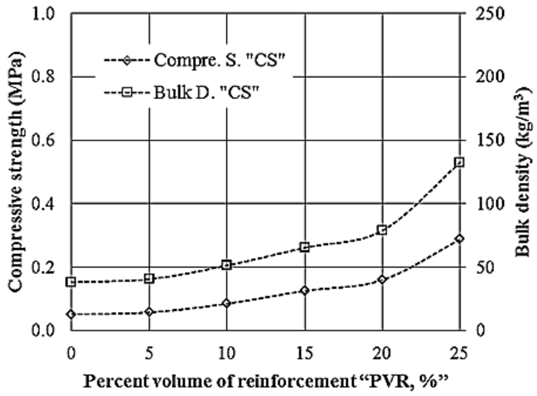

Fig. 5. Compressive strength versus bulk density at "PVR, %" for (CS).

3.3. *Compressive strength "P, MPa" via "PVR, %" and deformation "D, mm"*

Figs. 6 and 7 show, relation between percent volume of reinforcement "PVR, %", compressive strength "P, MPa" and deformation "D, mm" for each "TS and CS". It indicates that compressive strength "P, MPa" is affected by percent volume of reinforcement "PVR, %" and deformation "D, mm" for each "TS and CS". Compressive strength increases with increasing percent volume of reinforcement "PVR, %" and "D, mm" for each

"TS or CS". The obtained data illustrated that, compressive strength is increased from 0.05 to 0.89 "P, MPa" with increasing deformation "D, mm" from 3.08 to 12.98 and percent volume of reinforcement "PVR, %" from 0 to 25. The results showed that lowest value of "P, MPa" was 0.05, and highest value was 0.89 with increasing ratio of 94.40 %. While lowest value of deformation "D, mm" was 3.08 and highest value was 12.98 with increasing ratio of 76.27 % for cotton stalks. On the other hand, the compressive strength is increased from 0.05 to 0.29 "P, MPa" with increasing deformation "D, mm" from 3.08 to 7.50 and percent volume of reinforcement "PVR, %" from 0 to 25. The results showed that lowest value of "P, MPa" was 0.05, and highest value was 0.29 with increasing ratio of 82.76 %. While lowest value of deformation "D, mm" was 3.08 and highest value was 7.50 with increasing ratio of 58.90 % for corn stalks. From the previous results, it is clear that cotton stalks had highest values, better, of compressive strength and bulk density than corn stalks, may be because of the strong nature of cotton stalks structure than corn stalks.

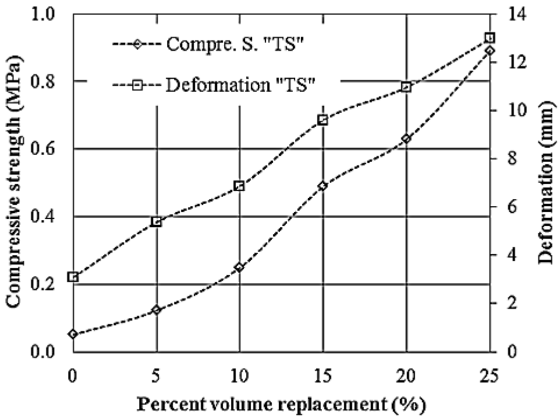

Fig. 6. Compressive strength versus deformation at "PVR, %" for (TS).

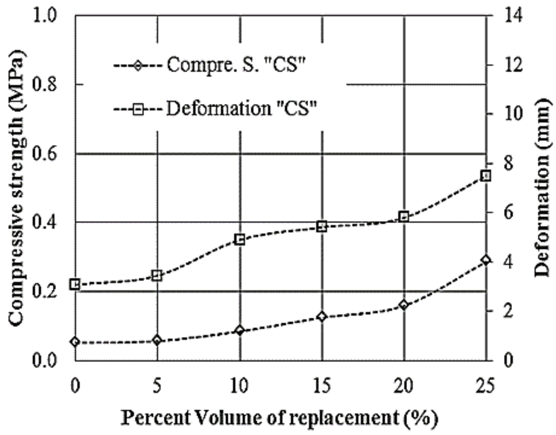

Fig. 7. Compressive strength versus at "PVR, %" for (CS).

3.4. Applied load "F, N" via deflection "d, mm"

Figs. 8 and 9 show, the relation between applied load "F, N" and deflection "d, mm" at different percent volume of reinforcement "PVR, %" for each "TS and CS". It shows that applied load "F, N" effect on deflection "d, mm" at percent volume of reinforcement "PVR, %" for each "TS and CS". The deflection "d, mm" is increased with increasing applied load "F, N" for each "TS and CS". The obtained data indicated that, the deflection "d, mm" is increased from 3.00 to 5.72 with increasing applied load "F, N" from 35.00 to 670.00 at different percent volume of reinforcement "PVR, %" from 0 to 25. The results showed that, the increasing ratio of deflection was 47.76 % when the applied load increasing by ratio of 94.78 %. The results indicated that the highest value of "F, N" was 670.00, at percent volume of reinforcement "PVR, %" of 25, and the lowest value of "F, N" was 35 at percent volume of reinforcement "PVR, %" of 0, for cotton stalks. on the other side, the deflection "d, mm" is increased from 3.00 to 5.25 with increasing applied load "F, N" from 35.00 to 330.00 at different percent volume of reinforcement "PVR, %" from 0 to 25. The results showed that, the increasing ratio of deflection was 42.86 % when the applied load increasing by ratio of 89.39 %. The results indicated that, the highest value of "F, N" was 330.00, at percent volume of reinforcement "PVR, %" of 25, and the lowest value of "F, N" was 35 at percent volume of reinforcement "PVR, %" of 0, for corn stalks. From the previous results, it is clear that cotton stalks were strengthen the highest values of applied load, better, and defection than corn stalks, may be because of the strong nature of cotton stalks structure than corn stalks.

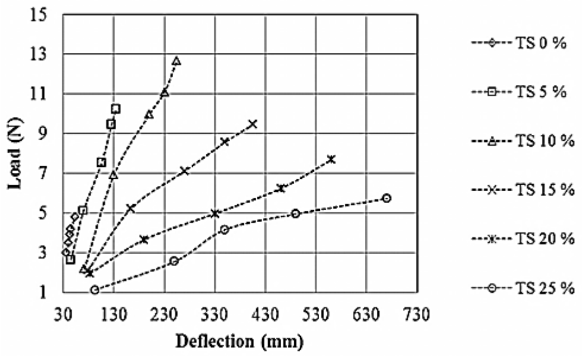

Fig. 8. Effect of load on the deflection at different "PVR, %" for (TS).

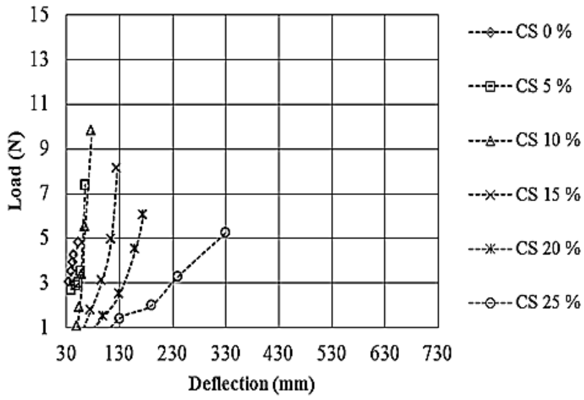

Fig. 8. Effect of load on the deflection at different "PVR, %" for (TS).

4. Conclusions

In this study, five different percent volume of reinforcement for each cotton stalks or corn stalks were incorporated with rigid polyurethane foam. Water absorption "Wa, %", bulk density "Bd, %", compressive strength "P, MPa", deformation "D, mm", deflection "d, mm" and applied load "F, N" of the produced composite identified as output parameters. Generally, for the produced composite, by increasing percent volume of reinforcement, the compressive strength "P, MPa", deformation "D, mm" and deflection "d, mm" was increased for each cotton and corn stalks. While, by increasing percent volume of reinforcement, water absorption "Wa, %" was decreased. The water absorption, bulk density, compressive strength and deformation were affected by percent volume of reinforcement for each cotton or corn stalks. As a result, the cotton and corn stalks were improved water absorption and compressive strength of rigid polyurethane foam. In a comparison between cotton and corn stalks, it was clear that cotton stalks better than corn stalks to incorporate with rigid polyurethane foam to improve some physical and mechanical properties.

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رغوة البولي يوريثان الصلبة المقواة ببعض المخلفات الزراعية

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الملخص العربي

أدت مشكلة تراكم المخلفات الزراعية في الحقول في مصر إلى العديد من مشكلات التوازن البيئي. وقد أدى عدم تدبير كيفية استخدام هذه المخلفات بطريقة تطبيقية مفيدة إلى تفاقم المشكلة مما جعلها في صدارة المشكلات البيئية. وحالياً يوجد مستويات عالية لتحويل المخلفات الزراعية بطرق مفيدة للمحافظة على البيئة والصحة العامة. وقد وجد في مصر، استخدام ألواح الفوم في عزل الحوائط، إلا أنه يعيبه ضعفه وقلة مقاومته. وقد يمكن التغلب على هذه العيوب بزيادة تدعيم الألواح باستخدام بعض المخلفات الزراعية مثل كل من حطب (القطن - الذرة)، مما يجعلها أكثر مقاومة للصدمات وايضا قد يعمل على تحسين بعض خواصها الفيزيائية مثل نسبة امتصاص الماء. ولقد أجريت هذه الدراسة في قسم هندسة المنشآت الزراعية والتحكم البيئي – كلية الهندسة الزراعية . جامعة الأزهر . القاهرة. ولمعرفة مدى إمكانية استخدام كل من حطب (القطن - الذرة) لتحسين بعض خواص الفوم الميكانيكية والحصول على منتج من الفوم مقاوم للكسر تم وضع نسب حجمية ٥ ، ١٠ ، ١٥ ، ٢٠ ، ٢٥٪ من حطب (القطن - الذرة) مع الفوم في قالب سهل الفك والتركيب مصنوع من الخشب بأبعاد ٥٠ × ٢٠٠ × ٣٠٠مم لإنتاج مركب من الفوم وكل من حطب (القطن - الذرة) على حدة.

وقد أجريت في هذا البحث ثلاث اختبارات هي:

١. حساب كل من النسبة المئوية لامتصاص الماء والكثافة الظاهرية.
٢. قياس مقاومة الانضغاط.
٣. قياس القوة المؤثرة والتشوه الناتج.

وكانت أفضل النتائج كما يلي:

- كانت أقل وأعلى قيمة للنسبة المئوية لامتصاص الماء هي (٥١,٧٩ و ٢٩٢,٨٪) عند عينات بها نسب تدعيم حجمية (٢٥ و صفر٪) لحطب القطن على الترتيب بنسبة انخفاض مقداره حوالي ٨٢,٣١٪ نسبة إلى العينات غير المدعمة.
- كانت أقل وأعلى قيمة للنسبة المئوية لامتصاص الماء هي (١٦٦,٩٩ و ٢٩٢,٨٪) عند عينات بها نسب تدعيم حجمية (٢٥ و صفر٪) لحطب الذرة على الترتيب بنسبة انخفاض مقداره حوالي ٤٢,٩٧٪ نسبة الى العينات غير المدعمة.
- كانت أقل وأعلى قيمة للكثافة الظاهرية هي (٣٨,٠١ و ٢٣١,٤٢ كجم/سم٣) عند عينات بها نسب تدعيم حجمية (صفر و ٢٥٪) لحطب القطن على الترتيب بنسبة زيادة مقدارها حوالي ٨٣,٥٨٪ نسبة الى العينات الغير مدعمه.
- كانت أقل وأعلى قيمة للكثافة الظاهرية هي (٣٨,٠١ و ١٣٢,٣٤ كجم/سم٣) عند عينات بها نسب تدعيم حجمية (صفر و ٢٥٪) لحطب الذرة على الترتيب بنسبة زيادة مقدارها حوالي ٧١,٢٨٪ نسبة الى العينات غير المدعمة.
- كانت أقل وأعلى قيمة لمقاومة الضغط هي (٠,٠٥ و ٠,٨٩) ميجا باسكال عند عينات بها نسب تدعيم حجمية (صفر و ٢٥٪) لحطب القطن على الترتيب بنسبة زيادة مقدارها حوالي ٩٤,٤٪ نسبة الى العينات غير المدعمة.
- كانت أقل وأعلى قيمة لمقاومة الضغط هي (٠,٠٥ و ٠,٢٩) ميجا باسكال عند عينات بها نسب تدعيم حجمية (صفر و ٢٥٪) لحطب الذرة على الترتيب بنسبة زيادة مقدارها حوالي ٨٢,٧٦٪ نسبة الى العينات غير المدعمة.

ومن خلال هذه النتائج يمكن استخدام كل من حطب (القطن - الذرة) من المخلفات الزراعية في تحسين بعض خواص الفوم الميكانيكية وبعض الخواص الفيزيائية مثل النسبة المئوية لامتصاص الماء، ولكن يفضل حطب القطن عن حطب الذرة مما يساعد في استخدامه في مجال أوسع. ونوصي باستكمال هذه الدراسة واستخدام مخلفات زراعية اخرى بأحجام مختلفة (نسب أعلى) وترتيبات مختلفة مستقبلا وإضافة قياسات أخرى.