The use of renewable agricultural by-products as building materials

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The main aim of this work was to study the possibility of using straw bales in building construction. To achieve that, it was urgent to investigate the physical, mechanical and thermal properties of two types of straw (wheat and barley) at different densities. Thermal performance and stability of the walls that made of these straw bales were also studied. The most important results could be summarized as follows:A. Physical Properties1.Bale dimensions were 60 - 72, 48 and 36 cm for length,width and thickness. The average bale length was 67 ± 4.84 cm with a coefficient of variation of 7.2 % for wheat, while it was 66±5.8 cm with a coefficient of variation of 8.8% forbarley.2.The average bale weight was 10.26 ± 2.57 kg with acoefficient of variation of 25.1 % for wheat straw, where it was 9.25±1.4 kg with a coefficient of variation of 15.3 % forbarley straw.3.The barley straw bales contain much more finer strawparticles compared to the wheat straw bales. That indicates that the barley straw bales with the same dimensions could have a higher weight than that of the wheat straw bales.4.It was found that, more than 50% of the wheat bales were having density ranged from 81-100 kg/m3, while more than 80% of the barley straw bales have density of 71-100 kg/m3.5.The average of moisture content was 11± 2.29% with a coefficient of variation of 20.8 % for wheat straw bales while it was I5.9±1.21% with a coefficient of variation of 7.6 % for barley straw bales.6.The results revealed that the equilibrium moisture content of the wheat straw increased with increasing the relative humidity but it decreased with increasing the temperature7.The equilibrium moisture content of barley straw is higher than that of the wheat straw or wheat straw get to the equilibrium with the ambient conditions faster than the barleystraw.8.The relative humidity has greater effect on the change of moisture content of bales compared to the effect of the temperature where, moisture content changes ranges from 2.4 — 2.8 % when temperature changed from 5 — 45 °C at 43 and 96 % relative humidity. While moisture con sent changes ranged from 7.5 — 8.9 % when relative humidity changed from 43 — 96 % at 5 and 45 °C.Summary and Conclusions310B. Mechanical PropertiesStress, strain, stress-strain curves, modulus of elasticity and poission’s ratio were determined for both wheat and barley straw types at different densities. The most important mechanical properties of these straw bales were as follows:-1-Stress increases with bale density, the average strength of bale in vertical orientation was higher by 27.4 % and 19.7 % than those of the horizontal orientation at all bale densities for wheat and barley straw bales, respectively. Also, barley bale resistance to deflection was higher than wheat bales.2-Strain was determined on vertical and horizontal directions for two different bale orientations (vertical and horizontal) at different densities for wheat and barley straw. It was found that the strain decreases with increasing bale density.3-Vertical Strain:-At vertical orientation, the average vertical strain ranged from 0.05 — 0.16 and 0.19 — 0.37 for wheat and barley straw hales, respectively.-At horizontal orientation, the average vertical strain ranged from 0.04 — 0.15 and 0.11 — 0.33 for the same previous order.-For the vertically oriented straw bales, the average of vertical strain was a high of 0.16 ± 0.11 at the lower densities balesSummary and Conclusions311312(81-90 kg/m3) to a low of 0.05 ± 0.03 at the high densities bales (131-140 kg/m3).- For the horizontally oriented bales, the vertical from 0.04 for 131-140 kg/m’ density to 0.15 fo have a density of 81-90 kg/m3.4- Horizontal Strain- At vertical orientation, the average horizontal from 0.0 — 0.04 and 0.1- 0.17 for wheat an bales, respectively.-Horizontal strain increases with increasing the bale density for wheat and barley straw bale.strain

ranged the bales thattrain ranged barley straw5- Stress—Strain RelationshipStress increases with increasing strain for al bales types, densties and orientations. Also the strain increases with increasing the stress. It can be observed that th bales with different densities vertically or horizontally orient -d under this load return to their own positions after a few i inutes fromremoving the load, that means that these bales i the elastic limits.Summary and Conclusions6- Modulus of Elasticity-The modulus of elasticity decreased gradually with increasing the applied load and increased with increasing baledensity.-The modulus of elasticity values of the vertically oriented bales were higher than those of the horizontal oriented balesfor both wheat and barley straw types.-The modulus of elasticity values of wheat bales ranged from 0.1 -- 0.9 MPa compared to 0.05 — 0.55 MPa for barley strawbales.The modulus of elasticity of wheat straw bales was higher than that of the barley straw bales, where, the modulus of elasticity ranged from 0.100 — 0.900 MPa and 0.1 — 0.800 MPa for vertical and horizontal orientations wheat bales, respectively. Meanwhile, it ranged from 0.08 — 0.30 MPa and 0.05 — 0.55 MPa, for vertical and horizontal barley bales,respectively7-Poisson's ratio-Poisson's ratio increased with increasing the applied load.-The results indicated that the Poisson's ratio in the longitudinal direction is much greater than that of the lateral direction for all bale types and densities.Summary and Conclusions313314- At vertical orientation, Poission's ratio rang d from 0.08 —0.17 and 0.24 — 0.31 for wheat and bark straw bales, respectively, while it ranged from 0.28-0.39 .nd 0.42 — 0.44 for the horizontally oriented wheat and barl y straw bales, respectively at horizontal orientation. The results showed that the highest value of oisson's ratio was 0.4 at the 101-110 kg/m3 bale density at the horizontal orientation compared to 0.17 at the vertical orie tation for the same bale density. The Poisson's ratio values o the vertically oriented bales were lower than those of the horizontally oriented bales at the different densities8- Relationships between these mechanical param ters and baledensity and load of both wheat and barley wer obtained byregression analysis with high coefficients of determ nation.C. Thermal PropertiesThermal conductivity was determined for bbarley straw bales at different densities and tempera The results indicated that the thermal conductiv with increasing temperature while it de increasing bale density to a certain limit and constant and then increased again to form what hooked shape.th wheat and ures.ty increased reased with eemed to be o-called the.Vtimmary and Conclusions- 2-Thermal conductivity ranged from 0.0414 - 0.0486 and 0.0353 - 0.0539 W/m.K for all bale densities and at different temperature for wheat and barley straw bales, respectively.- It is worthy to be mentioned that, the average values of thermal conductivity and thermal resistance at both 20.7 and 34.2 °C were much higher than those of at 10.3 °C- It could be noticed that the differences in the thermal conductivity and thermal resistance values as temperature changed from 10.3 °C to 20.7°C is higher than those values when temperature changed from 20.7 °C to 34.2 °C. This may be owed to that the thermal conductivity increased linearly with temperature and this increasing slowed down as temperature increment.- Heat capacity increased with bale density. It ranged from 164 - 276 and 138 - 196 ki/ms.K for the wall made from wheat and barley straw bales, respectively.- Thermal diffusivity decreased with increasing bale density. It ranged from 1.5 - 3.0 X10-7 and 1.8 - 3.9 X10-7 m2/s for wheat and barley straw bales, respectively.- Thermal effusivity ranged from 1.49 - 1.79 and 1.33 - 1.39 .1/m2 K has for wheat and barley straw bales, respectively.- The time required for thermal waves to transfer through wheat and barley straw bales ranged from 20.3 - 28.5, and 17.7 - 26.1 hour, respectively.Summary and Conclusions315D.Thermal Stability of BalesThermal stability of bales was investigated placing thebales in controlled atmosphere (23°C, and 80% relative humidity).Wheat bales reached stability faster than barley bales, where, alter 600 hours, for the same bale densities (71 — 100 kg/m3), the temperature differences ranged from 0.11 — 0.18 °C, and 0.34 — 0.51 °C, for wheat and barley straw bales, respectively.- Relative humidity with time, relative humidity differences ranged from 2.8 — 4.6 % and 4.3 — 6.1 % for wheat and barley straw bales wall, respectively.E.Temperature and relative humidity distribution inside straw wallTemperature and relative humidity were maintained at 35°C and 60 % at one side of the wall. Temperature and relative humidity were recorded at different locations vertically and horizontally oriented bales during the test time.- Temperatures were recorded at different locations on surface, at 12 cm, 24, 36 and 48 cm, for the horizontal orientation and on surface, at 12 cm, 24 and 36 cm, for vertical orientation. Bales used were having densities of 80, 100 and 111 kg/m3Summary and

Conclusions3164.44.4.4.441011140* 4for wheat straw type and 85 and 115 kg/m3 for barley straw type.- The temperature gradient decreased from outside (high temperature) towards the other side of wall (low temperature). The slope of this gradient increases with time.- The average relative humidity values were 58.01 ± 3.47 % and 54.01 ± 0.45 % at different locations for the horizontal and vertical orientation, respectively, at the beginning.The relative humidity at the center of the wall was 70.65 % while it was 73.57 % at 36 cm at the horizontal orientation. For vertical orientation, the relative humidity at the center of the wall was 69.71 % and it was 73.13 % at 24 cm, at the endof test.For the density of 115 kg/m3 at the beginning, the average relative humidity values were 60.32 ± 7.92 % and 79.15 ± 1.73 % at different locations for the horizontal and vertical orientation respectively.- For the density of 115 kg/m3at the end of the test, the relative humidity at the center of the wall was 63.39 % while it was 65.09 % at 36 cm at the horizontal orientation. For vertical orientation, the relative humidity at the center of the wall was 77.05 % and it was 80.61 % at 24 cm.