Experiments on olive husk-addition to masonry clay bricks on their mechanical properties, and their application and manufacturability as an insulating material

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Abstract. Clay has been used in Jordan as a building material for decades. This paper investigates the effects of adding olive husk—another locally available solid waste material—on the mechanical properties of the clay composite, and its modification of the ductility and thermal resistance for use as an insulating material.

Laminated Metal Tooling (LMT) process will be used to manufacture the dies required to cast and dry the test specimens. A discussion will also be included regarding the eligibility of the material for the use as a low-cost, high efficiency insulating material depending on the manufacturability of husk-enhanced clay sheets.

Introduction. The continuing inflation across the world, aggravated by the staggering increase of fossil fuel prices has prompted a justified introspection into the local environment for cheap sources of raw materials to be used as building materials and alternate fuels, along with energy saving technologies (such as enhancing the properties of insulating materials, especially ones readily available).

The use of mud in Jordan for building goes way back into history. Tuleitat Ghassul was a large Chalcolithic (4500-3200 BC) village in the Jordan Valley. Houses there were built of sun-dried mud bricks with roofs made of wood, reeds and mud. Some dwellings were based on stone foundations and many were planned around large courtyards [i].

Using additives to enhance the properties of clay bricks has been discussed in literature, especially in remote locations where clay are literally the building blocks of any masonry effort, because of availability and suitability. For example, Basha et al. [ii] have discussed stabilizing the soil using rice husk and cement. Other researchers have picked up on the importance of the recovery of what was once considered waste material, such as olive husk, such as discussed in [iii], where a comprehensive look at utilizing the by products of olive grinding (such as water and solid waste) in other domestic and industrial applications.

Many researchers have discussed the use of clay as a building material in Jordan. Most notably, B. A. Jubran et al. [iv], where the researchers have tested in compression clay specimens enhanced with straw and heat-treated. These clay bricks were used for housing in the rural areas of Jordan.

Experimental Setup. Four groups of specimens (CSHT_{25}, CSHT_{75}, CSHT_{100}, CSHT_{125}) each containing six specimens (a total of 24 specimens) were prepared. The classification was based on olive-husk content and temperatures. Six different percentages of husk were used, namely 0, 5, 10, 20, 30 and 40%, and all were dried on four different temperatures; 25 (ambient temperature), 75, 100 and 125°C.

The specimens were prepared by mixing clay, straw and olive husk with water. The percentage of water and straw was kept constant at 23% and 4% of the total weight for all specimens, as these are the optimum percentages from a previous study [iv]. Using a digital scale, the weights were measured, and the husk content added replaced the respective percentage of clay in each specimen.
The specimens then were cast in square moulds obtained from the Civil Engineering department of the Hashemite University, Jordan. Each mould produced three cubic specimens with 50 mm side length, as seen in Fig 1.

![Fig 1](image1.png)  
**Fig 1** (a) three specimens in mould, and (b) open mould

The die was lightly lubricated using SAE50 oil to facilitate specimen ejection after moulding. All specimens were left to dry naturally for 10 days, and then one group was left at 25°C, whereas the rest of the three groups were placed in an induction oven (available at the Engineering Workshops at the Hashemite University) for five hours, and each group was heated to its target temperature (75, 100 and 125°C). A typical specimen is shown in Fig 2.

![Fig 2](image2.png)  
**Fig 2** typical specimens, (a) 0% husk, (b) group of specimens

Higher temperatures than 125°C were not investigated, since they caused the oil within the husk to evaporate violently, causing noticeable grooves within the specimens. These grooves proved detrimental to the specimens and caused them to fail prematurely during compression testing.

Attempts to go over 50% (by weight) husk were not pursued because the high oil content hampers the necessary heat treatment of the specimens since the evaporating oil adversely affects the integrity of the specimens as mentioned above. High oil content also causes the specimens to be mushy causing them to stick to the walls of the moulds and decreases their castability and bonding, which produces low-strength specimens.

After the specimens are baked in the oven for 5 hours, the heating element is disengaged and the specimens are left inside until the oven reached ambient temperature (25°C). After the specimens
were removed from the oven, compression tests were conducted on each specimen at the Strength of Materials Lab using the Tensile Testing machine at the Mechanical Engineering department at the Hashemite University, as seen in Fig 3.

![Tensile testing machine and specimen during compression](image)

**Fig 3 (a) Tensile testing machine, and (b) specimen during compression**

The load cell of the machine has a rating of 300 KN and the crosshead speed used for all 24 specimens was 5 mm/s (0.2 in/s), which is a static rate of loading. Specimens were loaded till failure, which was signified by a sudden drop in the load reading recorded by the machine.

For measuring the thermal conductivity, three prismatic, flat specimens with dimensions 300 x 300 x 25 mm were prepared as seen in Fig 4.

![Specimen for measuring thermal conductivity](image)

**Fig 4 Specimen for measuring thermal conductivity**

The construction of the thermal conductivity specimens followed the same lines as in preparing the compression specimens. Three specimens were moulded with the following compositions:

1. H\(_{30}\): 30% husk, 20% water, 3% straw and the rest was clay
2. H\(_{30,\text{silica}}\): 30% husk, 25% water, 3% straw, 5% silica and the rest was clay
3. H\(_{100}\): 100% husk bound by a water-based binder

The specimens were placed in the thermal conductivity-measuring machine (P.A. Hiton) located at the Heat Transfer lab at the Mechanical Engineering Department of the Hashemite University, to measure their thermal conductivities. Heat flux enough to keep the input temperature at 50°C was applied, and silicon pads were used at the top and bottom of the specimens to ensure a perfect
Experimental Results.

Variation of husk content at constant temperature

The figures above plot the effect of increasing the husk content within the specimens at a constant temperature on their mechanical properties.

Variation of temperature at constant husk content
The six figures above show the effect of increasing the drying temperature at constant husk content on the mechanical properties of the specimens.

**Measurement of thermal conductivity.** The results for thermal conductivity for the three specimens (H₃₀, H₃₀silica and H₁₀₀) were found to be $K = 0.34$, $0.2$ and $0.09$ W/(m·K) respectively. The addition of silica to the second specimen along with the husk was to introduce a binding material that also has a low thermal conductivity (0.004-0.03). Using a 100% husk in the specimen H₁₀₀, it was observed that as the husk dries, it increases in volume at around 10-13%. This increase was in the plane normal to the horizontal plane of the mould since the mould walls in that direction confined the husk.

**Discussion.**

**Effect of husk content on mechanical properties.** By examining Fig 5, it can be noted that increasing the drying temperature has two distinct and opposite effects on specimens depending on husk content. The first effect is observed by comparing Fig 5 (a) and (d), where it is clear that there is an adverse effect of increasing the drying temperature on the strength and toughness on specimens void of husk. The second, opposite effect is observed when considering the same figures, where the maximum husk addition has shown great improvement of both strength and toughness in specimens, especially at the highest temperature of 125°C.

Generally, the temperature that has seen the best improvement in properties for all husk content percentages except for the 40% was 75°C as evident in Fig 5 (c). Strength and toughness have increased by increasing the husk with the drying temperature.

**Effect of drying temperature on mechanical properties.** The effect of drying temperature on the properties of specimens having constant husk content is shown in Fig 6. The Figures indicate
that for any given husk content, the best observed drying temperature is $75^\circ$ C, when the best strength and toughness was observed, except for specimens were the husk content exceeds 30% of the composition of the specimens. In such case, the best drying temperature observed was $125^\circ$ C, which gives superior properties as indicated in Fig 6 (f).

All the failure modes were typical brittle failures, where the crack initiated and propagated along a $45^\circ$ angle as seen in Fig 7.

![Brittle crack at 45°](image1)

(a) Brittle crack at 45° (a) initiation and (b) complete failure

![Springback effects on 40% husk](image2)

(b) Springback effects on 40% husk

An interesting feature that was noted during the course of the experiments was a noticeable springback effect, especially at a husk percentage of 40%, meaning that after the load was removed, the specimen retained its general original shape with some distortion, as seen in Fig 8.

The maximum springback was noted at 40% husk, while absolutely no springback was detected at 0% husk, where the specimen showed classical brittle material failure [iv]. Also, spring back was observed under all temperature ranges, except at $125^\circ$C. This has lead to the postulation that due to the relatively high oil content at 40% husk, the voids within the clay at the straw-clay interface is filled with a viscous slush composed of clay, husk and oil that allows any dislocations to move more easily than the cases without husk at all (0%).

To quantify this feature, a thorough testing was conducted on three specimens with 40% husk dried at $125^\circ$C. The resulting average stress-strain curve for the three is shown in Fig 9 (a). A clear linear portion of this curve is observed to strains up to 0.1. This portion is isolated in Fig 9 (b). A linear trend line is added to the curve, which has a 5.34 MPa slope, representing the modulus of elasticity of this specimen.

The importance of this relative ductility is emphasized when considering the manufacturability of husk-enhanced composites are considered for use as an insulator material, especially in sheet form. The specimen manufactured for the thermal conductivity experiment showed great integrity, which lends it to being used as a manufacturable insulator with extremely low (good) thermal conductivity.
Measurement of thermal conductivity. The results for thermal conductivity for the three specimens ($H_{30}$, $H_{30}$, silica, and $H_{100}$) were found to be $K = 0.34$, $0.2$ and $0.09$ W/(m·K). The results have shown that while adding silica has lowered the thermal conductivity, it has adversely affected the integrity of the specimens. The $H_{100}$ specimens had the best observed integrity to weight ratio, since the husk expands in volume as it dries, and thus it can be chosen to be the best insulating material from both points of view, lowest thermal conductivity, and best mouldability.

Conclusions. This paper investigated the effect of adding unburnt olive husk to clay bricks on their mechanical properties and thermal conductivity. The amount of husk added was varied, along with the drying temperature. The Upper limit of husk content was kept at 40%, since higher percentages cause the bricks to remain in a mushy state and it was not possible to mould them. Also, higher temperatures than 125° C was not attempted at high husk content (above 20%) because it adversely affects the integrity of the specimens due to the evaporation of the oil contained within. From the results obtained, the best recommended drying temperature for specimens was found to be 75° C for all husk content except for 40%, where a temperature of 125° C was found to be most effective. This particular combination of husk content and drying temperature produced a material with superior properties in terms of toughness and strength, which reflected greatly on their manufacturability into sheets that can be used as an insulating material. This is coupled by the fact that this specimen scored the best thermal conductivity results (around 0.09 W/m·K), which makes it extremely attractive as an easy to produce alternative to expensive or hazardous insulating materials.

References

[iii] Information on http://www.oliveoilsource.com/olive_waste.htm#Overview
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