Effect of Adding Sawdust to Cement on its Thermal Conductivity and Compressive Strength

Sanaa A Hafidh1, Thamer A Abdullah2, Fanar G Hashim2 and Bashar K Mohmoud3
1 Energy and Renewable Energies Technology Center, University of Technology, Iraq
2 Applied science department, University of Technology, Iraq
3 Ministry of Higher Education and Scientific Research, Iraq

E-mail: 100285@uotechnology.edu.iq

Abstract: In this practical study, the thermal conductivity and compressive strength of a number of cement mortar and sawdust mixtures were measured. This study aims to analyze the possibility of using these mixtures as thermal insulators in the building parts. The materials used in the study were ordinary Portland cement available in the local Iraqi market, sand, and sawdust. Samples were prepared according to American standards. Sawdust in two different sizes (greater than 50 mm and less than 1.4 mm) was added to the cement. The study results showed that adding sawdust caused an apparent decrease in the mixture's thermal conductivity, which means an improvement in the thermal insulation of the mixtures. The decrease in conductivity also raised with the sawdust mass fraction increase. The thermal conductivity of sawdust and cement mixtures increased when using small sawdust (less than 1.4 mm) compared to the second case (sawdust of large size above 5 mm). The mixture's thermal conductivity decreased with the increase in the water curing period, and the decrease in conductivity increased with this period. Increasing the sawdust mass fraction resulted in a decrease in the studied mixtures' compressive strength, and this resistance decreased more when using sawdust of smaller sizes (less than 1.4 mm). The compressibility strength of all the studied products increases with the increase in the treatment time with water due to the cement's properties.

Keywords: Ordinary Portland cement, Mortar, wood sawdust, Compressive strength, Thermal conductivity.

1. Introduction
Energy is generally the primary driver of all activities in societies [1]. Hence, the interest in energy storage and saving is an essential matter in the field of construction and ages [2]. Also, preventing heat from escaping into the building, especially in hot areas, means maintaining adequate comfort conditions for residents. Also, preventing heat leakage from inside the building to outside in cold regions means preserving occupants' comfort conditions and reducing fuel spent on heating. Hence the interest in insulating the building with insulating materials with low conductivity [3]. Cement is a suitable building material, as it has a low thermal conductivity, which makes it a good insulator. It is also a good heat store. These specifications made its use common in construction in many countries, including Iraq. The adoption
of the technique of adding additives to cement is not new and is intended either to improve thermal insulation or thermal storage. Researchers experimented with adding various materials with good insulating properties such as plastic, phase change materials, cork, and sawdust [4]. The use of local materials in construction means saving the cost of construction and facilitating the process of transporting and storing materials. Using local building materials is a solution to economic problems plaguing developing countries. Cement in fillings is necessary to improve bonding between bricks or stone used in construction, thus increasing the construction's strength and durability and achieving savings in cement compared to mortar. Also, adding a small proportion of the additive is sufficient to preserve the sand/gravel ratio higher than 1. If the mixture contains gravel, then the material label is “loaded sand concrete” [4]. Reference [5] used local materials and reused various wastes to create lightweight structural sand concrete and improve its thermal properties while preserving its mechanical performance. Reference [6] focused on the possibility of creating a more sustainable lightweight concrete, and the product was called Mineral Wood Concrete (MWC). In this work, a portion of the cement was replaced by wood sawdust produced from carpentry works and was considered waste. The study achieved three crucial goals by using sawdust as an additive: first, preserving natural raw materials, second: recycling the use of waste instead of burning and destroying it, and finally: saving energy as a result of reducing the thermal conductivity of cement and increasing its thermal insulation. The use of wood sawdust can be considered a correct way to develop sustainable green concrete with low thermal conductivity, high thermal resistance, and low weight.

Many researchers have proposed different scientific methodology types and several processors to facilitate the use of many types of waste to produce lightweight composite concrete [7]. For example, Reference [8] worked on installing and producing a new building material called Wood-Crete. This material was made by adding several materials (sawdust, waste paper, and root lime) to cement. During the study, the material was evaluated through several tests and treatment methods and the factors that could negatively affect the performance of the proposed compounds. From a study of the properties of Wood-Crete, it is clear that it is possible to produce sustainable lightweight blocks with good insulation. The researchers noted that the properties of Wood-Crete were positively related to the addition of paper waste to cement, and the effect of this addition dominated its properties, such as thermal conductivity and compressive strength. Reference [9] used natural cement, sand, and palm fibers (DPF) to produce a material with suitable properties as an insulator for buildings. This material was given using some fiber concentrations (from 0% to 30% by weight). Three different sizes of fibers were used in the study. Reference lesson. [10] Physical and mechanical properties of wood gypsum compounds. The additives used consisted of sawdust produced from the mixed wood waste of various sizes. The study showed that increasing the amount of wood waste reduces product density and hardness. Also, adding sawdust in high proportions causes a slight decrease in thermal conductivity. Reference [11] used by-products to treat wood by substituting natural sand to produce a lightweight mortar. Wood products and furniture manufacturers produce sawdust and bits of side pieces from logs to rectangular shapes. It is also produced by cutting, drilling, and milling processes when cutting a log either from logs or during the final products’ preparation. The sawdust is often collected in filter bags or dust collectors. Reference [12] studied the production of environmentally friendly and thermally efficient normal and lightweight concrete with different amounts of sawdust as an alternative to sand. Conventional NWC contains 0, 5, 10, and 15% sawdust, and LWC contains 0. In this paper, the effect of adding sawdust on the thermal conductivity and compressive strength of sand concrete will be studied. The study benefited from building materials available in the local Iraqi market.

2. Materials
Ordinary Portland cement was used as the primary material. This cement was selected because of its availability in Iraqi local markets at a reasonable cost. It is widely used in this country in construction works. Portland cement is characterized by the specific gravity of (3.15), and the ratio of water to cement
(W/C) is kept equal to (0.3). Natural wood sawdust was used in this study as an additive. Two additive types were selected depending on particle size (larger than 5 mm and less than 1.4 mm). Wood sawdust has a specific gravity of (1.25-1.55). This material density ranges between 750 kg/m³ to 800 kg/m³. Its tensile strength is about 1500 N/m², while the elastic modulus ranges from 10 Mpa to 17 Mpa. It absorbs moisture at a rate of 7-9%.

3. Measuring

3.1. Thermal conductivity
In this study, Lee's disk made in England by (Griffen and George Company) was used. Disc Lee is used to evaluating the samples’ thermal conductivity. It consists of three copper discs and a heater. The tablets' surfaces are kept clean, and the samples are placed in good contact with the tablets to ensure heat transfer in the best possible way. An electrical current is supplied to the disc heater by supplying it with a voltage difference of 6 volts. After the thermal equilibrium is achieved (after approximately 45 minutes), the disc temperatures are measured.

$$12IV=\pi re\ T+T+2\ \pi re\ T+dT+dT+dTABAAAsABBBCC2$$  \hspace{1cm} (1)

Where:
I: the current of the electrical circuit, V: potential difference, r: disk radius (mm), TA, TB, and TC: the three tablet temperatures, dA, dB, and dC: the thickness of copper discs, ds: the thickness of the sample, e: represents a value for the thermal energy flux's quality across the samples’ cross-sectional area per unit time (W/m² °C).

$$T-T2=11BAk=\epsilon T+(ddT+(dT))ssBAAAdr4$$  \hspace{1cm} (2)

Where:
k: the coefficient of thermal conductivity (W/m °C).

3.2. The compressive strength
The standard BS1881: Part 116: 1989 was used in samples’ measuring compressive strength. Compression resistance is measured with cubic samples with a side length of 100 mm, and the compression press is an electrical test machine of 2000 kN with a maximum load of 5 MPa/min. The experiments were repeated for each sample three times, and the arithmetic mean of the results was adopted to reduce uncertainty and confirm repeatability. Samples were treated with water for 28 days using tap water.

Pressure = force/area  \hspace{1cm} (3)

The pressure is measured in (MPa), the strength is measured in (N), and the area is measured by (mm²).

4. Result and discussion

4.1. Thermal conductivity
Cement is used in building walls, foundations, and structures. Therefore, the thermal behavior of the cement is of particular importance. Working in areas with high solar radiation intensity and high ambient temperatures, the building material's thermal insulation must be good, as it insulates the outside heat from entering the building and can store heat. Hence, the building material's thermal conductivity should be small; good thermal insulation is provided in such a case. This does not mean that the thermal conductivity is not desirable in some other applications. High thermal conductivity reduces the thermal gradient in the concrete structure by taking advantage of the conductivity and insulation properties. Figure 1 shows the effect of adding sawdust (mixed with concrete as fiber and chopped flour) in two different proportions (greater than 50 mm and less than 1.4 mm) on the thermal conductivity. Adding
sawdust with a size greater than 5 mm reduces the mortar's thermal conductivity more than the addition of sawdust with particles measuring less than 1.4 mm. The first case's low thermal conductivity (adding sawdust greater than 5 mm) is due to the agglomeration of these fine particles that agglomerate during mixing with cement. When adding natural sand, the thermal conductivity increases due to the increase of its spread and preventing the sand from clumping it. As for mixing it with sawdust, it causes its decrease, as shown by the references [2, 3, 4, 5, 6, 7].

The concrete is treated by adding water to it, and the curing time while treating the concrete with water affects the product. The thermal conductivity reduced due to the addition of water, which caused water-saturated pores during the samples' curing period, as Figures 2 and 3 depict.

**Figure 1.** Effect of added sawdust mass fraction on products thermal conductivity.

**Figure 2.** Effect of water curing time on products thermal conductivity for the first case (particles size larger than 5 mm).
The above two figures show that the decrease in thermal conductivity in the case of adding sawdust greater than 5 mm to cement is more significant than the second case, as both of the aforementioned reasons combine to maximize the decrease in conductivity. In Figure 3, for the case of adding sawdust less than 1.4 mm, and after a 15-day immersion period, the thermal conductivity decreases for the case of adding 10% sawdust to be equal to its counterpart in the second case, but at all other immersion periods, we find that it is higher. By comparing the results of the two figures, the thermal conductivity of the case of adding sawdust greater than 5 mm decreased by 49.74%, 72.6%, and 89.14% for each of the sawdust additions by 10%, 20%, and 30%, respectively, compared to cement. As for the case of adding sawdust measuring less than 1.4 mm, the thermal conductivity of the cases of adding sawdust by 10%, 20%, and 30% reduced by 34.5%, 51.77%, and 43.14%, respectively compared to cement. When comparing the results of Figures 2 and 3, the thermal conductivity of the case of adding sawdust with a measurement of less than 1.4 mm, the thermal conductivity increased by 30.3% for the case of adding sawdust by 10%, 107.4% for the case of adding 20%, and in the case of addition 30% sawdust, the increase in thermal conductivity reached 343.9%.

4.2. Compressive strength
Figure 4 (case of adding sawdust with a size greater than 5 mm) and Figure 5 (case of adding sawdust of size less than 1.4 mm) show an analysis of the relationship between the compressive strength of mixtures and the effect of sawdust type on the compressive strength of the product during a cure period lasted for 28 days. The compressive strength of all products increased with the increase in the curing period due to the interaction of water and cement, while this resistance decreased with the increase in the amount of added sawdust due to the increase in porosity resulting from the penetration of water into the fibers and sawdust particles. The most significant decrease in compressive strength occurs when adding 30% of sawdust.
Figure 4. Effect of water curing time on the compressive strength of products of the first case.

Figure 5. Effect of water curing time on the compressive strength of products of the second case.

In Figure 4, the products' compressive strength decreased by 28.7%, 54.6%, and 69% for 10%, 20%, and 30% addition cases of sawdust of size greater than 5 mm compared to cement. Figure 5 shows that the decrease in the products' compressive strength was 48.8%, 57.5%, and 75.6% for the case of adding 10%, 20%, and 30% of sawdust, measuring less than 1.4% compared to cement. When comparing the two figures' results together, the reduction in compressive strength of a case of sawdust measuring less than 1.4 mm is higher than the second case. When adding 10% sawdust (condition less than 1.4 mm), the decrease in compressive strength was 28.22% when adding 10% sawdust, 6.7% when adding 20% sawdust, and 21.3% when adding 30% sawdust. These results confirm the properties of natural mulch, which caused a decrease in compressive strength. The compressive strength using the fibers is affected by the measurement of these fibers. Whenever it is with small measurements, the results are better than the case of large sizes.
5. Conclusions
In this study, a change in the properties of cement's compressive strength and thermal conductivity was tested when sawdust of two different sizes (greater than 50 mm and less than 1.4 mm) was added. The addition of sawdust caused a clear reduction in the mixture's thermal conductivity, and the decrease in conductivity raised with the higher sawdust. Using sawdust mass fraction of small size (less than 1.4 mm), the conductivity increased more than the second case (sawdust of large size higher than 5 mm). The water treatment period decreases thermal conductivity; as this period is getting higher, the conductivity decreases. The compression resistance of cement and sawdust mixtures decreases by increasing the percentage of sawdust in the mixture, and this resistance decreases when using sawdust of small sizes (less than 1.4 mm). The compressive strength of all products raised when the curing time became longer due to cement properties.

6. References
[1] Chaichan M T, Kazem H A 2019 Generating Electricity Using Photovoltaic Solar Plants in Iraq (Springer, ISBN: 978-3-319-75030-9)
[2] Ali H A Al-Waeli, K Sopian, Hussein AKazem and Miqdam TChaichan 2018 NanoFluid Based Grid Connected PV/T Systems In Malaysia: a Techno-Economical Assessment (Sustainable Energy Technologies and Assessments) vol 28 no pp 81–95
[3] Al-Waeli A H A, Kazem H A, Sopian K and Chaichan M T 2018 Techno-Economical Assessment of Grid Connected PV/T using Nanoparticles and Water as Base-Fluid Systems in Malaysia (International Journal of Sustainable Energy) vol 37 no 6 pp 558–578
[4] M Bederina, L Marmoretb K Mezreb, M M Khenfer, A Bali and M Quéneudec 2007 Effect of the Addition of Wood Shavings on Thermal Conductivity of Sand Concretes: Experimental Study and Modelling (Construction and Building Materials) vol 21 pp 662–668
[5] Junli Luo, Xin Zhang, Jiaming Zhao and Zhisheng Xu 2019 Fire Experiment on Temperature Distribution in an Underground Vertical Car Park (Case Study in Thermal Engineering) vol 15 p 100537
[6] Corganti S P, Kindinis A 2009 Improving Environmental Sustainability of Concrete Products: Investigation on MWC Thermal and Mechanical Properties (Energy and Buildings) vol 41 no 11
[7] AlmirSales, Francis Rodriguesde Souza and Fernando do Couto RosaAlmeida 2011 Mechanical Properties of Concrete Produced with a Composite of Water Treatment Sludge and Sawdust (Construction and Building Materials) 25 (6) 2793-2798.
[8] Eboziegbe PatrickAigbomian and Mizi Fan 2013 Development of Wood-Crete Building Materials from Sawdust and Waste Paper (Construction and Building Materials) vol 40 pp 361–366
[9] Nadia Benmansour, Boudjemaa Agoudjil, Abdelkader Gherabi, Abdelhak Kareche and Aberrahim Boudenne 2014 Thermal and Mechanical Performance of Natural Mortar Reinforced with Date Palm Fibers for use as Insulating Materials In Building (Energy and Buildings) vol 81 pp 98–104
[10] M J Morales-Conde, C Rodriguez-Liñán and M A Pedreño-Rojas 2016 Physical and Mechanical Properties of Wood-Gypsum Composites from Demolition Material in Rehabilitation Works (Construction and Building Materials) vol 114 pp 6–14
[11] Valeria Corinaldesi, Alida Mazzoli and Rafat Siddique 2016 Characterization of Lightweight Mortars Containing Wood Processing by-Products Waste (Construction and Building Materials) vol 123 pp 281–289
[12] Wisal Ahmed, Rao Arsalan Khushnood, Shazim Ali Memon, Saajid Ahmad, Waqas Latif Baloch and Muhammad Usman 2018 Effective use of Sawdust for the Production of Eco-Friendly and Thermal-Energy Efficient Normal Weight and Lightweight Concretes with Tailored Fracture Properties (Journal of Cleaner Production) vol 184 pp 1016–1027.