Physical and mechanical properties of sawdust cement mortar treated with hypochlorite

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Abstract. In this study properties of cement mortar containing sawdust have been studied. Different percentages of sawdust have been used as (10%, 20%, 30%, 40%, 50%) of the total volume of dry contents. Sawdust used has been collected as a by-product of carpentry factories and has been used in three ways: first pure sawdust second treated with hypochlorite without washing and the third is treated with hypochlorite and washed with water and dried. Compressive strength test has been performed at 7 days and 28 days, while flexural strength, dry density and absorption have been performed at 28 days. The results showed an enhancement of compressive strength, decrease in dry density and absorption for the mortar containing treated and washed sawdust with the increase of sawdust content in the mixture.

1. Introduction
In the last few decades, due to the huge amount of industrial waste, it has become necessary to treat and recycle these wastes in a safe and environmentally friendly manner. Concrete is one of the most important construction materials used in construction due to its characteristics in terms of strength, durability, and ability to give the required shape. In addition to the availability of materials involved in its manufacture. Concrete is characterized as or high density (2200 – 2400) kg /m³ and this increases dead loads on foundations and other structural components. So the researches focus on lightweight concrete.

The use of vegetable fibers in concrete started in the last century. The use of vegetable fiber in concrete is of great benefit in minimizing the cost of materials entering the concrete industry, reducing concrete weight and wastes being disposed of in a safe, effective and environmentally friendly manner. The use of sawdust which is by product of carpentry industry attracts the attention of researchers.

In 2001, Ravindarajah et al. [1], investigated the addition of sawdust to cement mortar to produce a lightweight load-bearing blocks, with the addition fly ash, lime and calcium chloride. The results revealed that up to 12%(by weight) addition of sawdust ,the compressive strength of concrete blocks will be above 12.5 MPa(required quality for load-bearing blocks).Some of mechanical properties of sawdust cement mortar (compressive strength and hardness) have been studied by Bdeir [2],with sawdust replacement of fine aggregate. Different percentages of sawdust have been used, the results showed a decrease in compressive strength and hardness values with high percentages of sawdust. Cost analysis was done based on unit of mortar (1.0 m³) which showed a cost saving with the use of sawdust in mortar.

As for Moreira et al. [3] studied the possibility of making lightweight concrete blocks by replacing part of the fine aggregate with treated sawdust in two ways: first by washing with an alkaline solution (lime) and the second way by immersing the sawdust in an aluminium sulphate solution. The result proved the effectiveness of treatment by aluminium sulphate compared with the treatment by lime.
Abdullah et al. [4] studied the effect of adding treated sawdust by dam lock material and untreated one on the proportion of Ferro cement as partial replacement of fine aggregate. The samples tested under static and dynamic loads and thermal conductivity has been measured. The results revealed an enhancement in performance of mortar mixes and thermal conductivity has been improved and the best ratio was 30% replacement of sawdust of fine aggregate.

The use of sawdust as partial replacement of sand has been investigated by Cheng et al.

Xing et al. [6] studied the possibility of making lightweight concrete block using the method vibrocompression by replacing part of the fine aggregate with sawdust. The physical properties of concrete block, such as compression strength and thermal conductivity were studied.

Gopinath et al. [7] studied the physical properties of concrete by replacing part of the fine aggregate with sawdust and replacing part of cement with sawdust ash. Concrete and mortar samples have been casted. Physical properties have been performed such as slump test, compression strength. The results found the possibility of using sawdust in structural members for residential buildings such as slabs, columns, beams, foundations and finishing which has a significant economic impact.

Alsharie et al. [8] studied the physical properties of lightweight mortar using a fine aggregate of limestone and pumice stone, by treating them with a solution of hypochlorite (NaOCl). The results proved that treatment with a hypochlorite solution led to an increase of compression strength of mortar and also led to the improvement of physical properties of fine aggregate such as specific gravity, absorption, and corrosion resistance and compression strength.

Mhalhal [9] studied the effect of using limestone treated with hypochlorite on the mechanical properties of self-compacted mortar. Samples of mortar have been cast using limestone as fine aggregate treated by hypochlorite. The results compared with the ordinary fine aggregate samples and untreated limestone samples then the effect of treatment by hypochlorite on soft mortar was also studied. The results showed improvement in the mechanical properties such as compression and flexural strength for samples with treated limestone, and also showed improvement in workability and flow time of soft mortar. Nine panels of cement mortar have been casted and tested under influence of four-point loading; the result showed that the panels made by a fine aggregate of treated limestone gave a strength and rigidity more than the other panels.

Memon et al. [10] studied the physical properties of concrete by adding certain percentages of sawdust to the concrete mix. Density, compression strength, workability and thermal conductivity have been measured. The results proved a decrease in workability, density, and compressive strength with a decrease in thermal conductivity.

Gil et al. [11], Investigated the mechanical behavior of sawdust cement mortar, different percentages of sawdust were added, scanning electronic microscope used to investigate mechanical properties such as compressive strength and elastic modulus. The results showed that although compressive strength and elastic modulus have reduced with the increase of sawdust content, but there was a positive effect of post cracking behavior and an improvement in ductility of mortar.

Sasah et al. [12], studied the behavior of standard masonry mortar containing sawdust. Wide range of sawdust percentages up to 50% replacement of sand were investigated. Results revealed that there is a possibility of replacing the sawdust with fine aggregates in masonry units and with 8% and 13% percentages of replacement, mortar properties are conformable with theoretical values.

In this research the effect of the use of treated sawdust with hypochlorite has been studied, sawdust has been added as an addition to the mortar mix. Samples with ordinary untreated sawdust, treated without washing sawdust and the others treated and washed sawdust were prepared. The results showed an increase in the compressive strength and decrease in the absorption of sawdust mortar with treated and washed sawdust.
2. Materials and Methods
In this research, the fine aggregate was used with ordinary Portland cement and water. Sawdust was added in different percentages of the total dry materials volume.

- Cement: ordinary Portland cement used and tested physically and chemically in according to the Iraqi standard specifications 1984 [13], the results shown in Table 1. These tests were performed in the laboratories of the department of chemical engineering and the laboratory of construction materials at the faculty of engineering.

Table 1. Results of Cement Tests

| Test                          | Result | Specification       |
|-------------------------------|--------|---------------------|
| Loss when burning            | 1.99%  | No more than 4%     |
| Insoluble substances         | 1.4%   | No more than 1.5%   |
| Alumina content (Al$_2$O$_3$) | 5.1%   | No more than 3.5%   |
| (SO$_3$) content             | 2.1%   | No more than 2.8%   |
| (Fe$_2$O$_3$) content        | 5.4%   | No more than 6.0%   |
| (Mgo) content                | 4.3%   | No more than 5.0%   |
| (SiO$_2$) content            | 18.877%| No more than 21%    |
| Compressive strength         | 20.4   | Not less 15 n/mm$^2$|
| Initial setting strength     | 52     | Not less 45 minute  |
| Final setting time           | 8.5    | No more than 10 hours|
| Fineness (kg/m$^2$)          | 999.75 | Not less 250 kg/m$^2$|

- Fine aggregate: it is ordinary sand taken from the local queries. Clean and free of strange material, and impurities it is subject to all laboratory tests, it conforms to the Iraqi standard specification (No. 45)1984 [14]. Table 2 shows the results of the tests. The chemical examination was performed in the laboratories of the department of chemical engineering at the Faculty of Engineering. Table 3 shows the sieve analysis test results for fine aggregate, which is carried out in the laboratory of the construction materials at the Faculty of Engineering.

Table 2. Results of chemical analysis of fine aggregate

| Test       | Result | Determinate |
|------------|--------|-------------|
| gypsum content | 0.131% | 0.5%        |
| Total dissolved salts | 1.22% | 5%          |

Table 3. Results of sieve analysis of fine aggregate

| Sieve No. | Zone (2) % | Combined passing percentage |
|-----------|------------|-------------------------------|
| 9.5       | 100        | 100                           |
| 4.75      | (90-100)   | 100                           |
| 2.36      | (75-100)   | 75                            |
| 1.18      | (55-90)    | 65                            |
| 0.600     | (35-59)    | 55                            |
| 0.300     | (10-30)    | 30                            |
| 0.150     | (0-10)     | 25                            |
| 0.075     | (0-5)      | 0                             |

- Water: the water used in mixing the mortar is the tap water available in the laboratory.
- Sawdust: shown in Figure 1, obtained from the local carpentry factories, it is clean and free of impurities, accidental or dust product it was sifted by sieve (2.36) mm. It is used in three cases.
  1- Using sawdust in dry condition, without any treatment.
  2- Using sawdust after treatment with hypo chloride and without washing.
3- Using sawdust after being treated with hypo chloride and submerged in water for 24 hours and dried. In all the three cases the sawdust was dried then used.

![Figure 1. Sawdust used](image1)

![Figure 2. Molds used](image2)

- Hypochlorite: using bleaching substance available in the local market trademark "perous" The percentage of active substance sodium hypochlorite is " 15% NaOCl" according to the information installed on the product.

The sawdust was processed by mixing it with hypochlorite by (0.75) liter for one kilogram of sawdust then dried or washed and dried as required.

### Table 4. Quantities of materials used

| Sample | Cement kg | Fine aggregate kg | w/c% | Sawdust gm |
|--------|-----------|------------------|------|------------|
| 1      | 1.25      | 2.5              | 50   | 45         | 45         | 228       |
| 2      | 1.25      | 2.5              | 50   | 50         | 55         | 455       |
| 3      | 1.25      | 2.5              | 60   | 55         | 60         | 683       |
| 4      | 1.25      | 2.5              | 65   | 60         | 60         | 910       |
| 5      | 1.25      | 2.5              | 85   | 65         | 60         | 1.138     |

where (1)* is Untreated sawdust mix, (2)* is treated sawdust mix (without washing), and (3)* treated and washed sawdust mix.

2.1 Preparation of samples

Examination models were prepared by casting cubes of cement mortar with dimensions of (50 *50 * 50) mm Figure 2 and prisms with dimensions of (40 * 40* 160)mm for determining the compression strength, absorption density and flexural strength.

Dry materials were mixed (cement, fine aggregate and sawdust) well and then adding water in a dry material, mixing them until they become homogeneous dough then pour into the model after lubricating the internal surfaces to prevent mortar adhesion by the mold. Molds are placed on the vibration table models to get competed. Then the surfaces should be equaled and left in the air for 24 hours, other than they are removed from the molds and immersed in clean water till the time of examination.

The process of mixing mortar and model casting and processing was according to the American standards ASTM C 305[16].The water percentage is variable according to the sawdust percentage in the mixture as shown in Table 4, several cases of mortar were studied as shown below. Casting cubes and prisms of pure mortar (reference mix), they were cured in water for 7 and 28 days then tested in the laboratories. The results are shown in Table 5. Casting cubes and prisms of cement mortar using sawdust without treatment, they were cured in water for 7 and 28 days, and then tested; the result is shown in Table 6. Casting cubes and prisms of cement mortar using sawdust after being treated by hypochlorite. They are cured in water for 7 and 28 days then tested. The result is shown in Table 7.
Casting cubes and prisms of mortar with sawdust after being treated with hypochlorite and washing it by soaking it in water for 24 hours then dried, and then tested. The results are shown in Table. 8. The compressive strength test was performed by lifting models from the curing tank and drying them with clean cloth, then placing them in the compressive strength device shown in Figure 3, increasing the load gradually until the specimen fails. This test is done according to the American standard ASTM/C 109 [17]. The flexural strength test is performed by lifting the specimen from the curing tank and dried them with a clean cloth and then placing them in the flexural strength device shown in Figure 4, and increasing the load gradually until they fail. This test was performed according to the American specification ASTM/ C 348[18]. Absorption and density tests were performed by lifting the specimens from a curing tank, drying them with a clean cloth, weigh them in the wet state and record the wet weight (W2), then inserting them in an oven and weigh them in the dry state and record the dry weight (W1).

3. Calculations

Compressive strength of mortar cubes is calculated according the following law:

\[ \sigma = \frac{P}{A} \]  

\[ \sigma = \text{Compressive strength (N/mm}^2\text{)} \].
\[ P = \text{failure load (N)} \].
\[ A = \text{area (mm}^2\text{)} \]

When the modulus of rupture was calculated by subjecting the load on the middle span (one point load)

\[ MR = \frac{3PL}{2bd^2} \]  

\[ MR = \text{modulus of rupture (N/mm}^2\text{)} \].
\[ P = \text{failure load (N)} \].
\[ L = \text{distance between supports (100 mm)} \].
\[ b = \text{width of section (40 mm)} \].
\[ d = \text{depth of section (40 mm)} \].

The absorption is calculated using the following equation:
Absorption \[= \frac{W_2 - W_1}{W_1} \] ....................................................(3)

\[W_1 = \text{dry weight (gm)}\]
\[W_2 = \text{wet weight (gm)}\]

Table 5. Results of reference cement mortar

| w/c% | Compressive strength (N/mm\(^2\)) | Modulus of rupture (N/mm\(^2\)) | Absorption % | Density kg/m\(^3\) |
|------|-----------------------------------|-------------------------------|--------------|-------------------|
|      | 7 days | 28 days |      |                  |                  |
| 0.45 | 26.8    | 40.1    | 11.3 | 7.454            | 2147             |

Table 6. Results of sawdust cement mortar (untreated sawdust)

| Sawdust % | w/c% | Compressive strength (N/mm\(^2\)) | Modulus of rupture (N/mm\(^2\)) | Absorption % | Density kg/m\(^3\) |
|-----------|------|-----------------------------------|-------------------------------|--------------|-------------------|
|           |      | 7 days age | 28 days age |                  |                  |
| 10        | 50   | 22.6     | 36.9     | 9.285          | 6.951          | 1933             |
| 20        | 55   | 20.2     | 29.3     | 9.113          | 7.281          | 2013             |
| 30        | 60   | 11.1     | 17.3     | 5.477          | 9.158          | 1883             |
| 40        | 65   | 8.0      | 14.2     | 4.416          | 9.359          | 1853             |
| 50        | 85   | 11.0     | 8.6      | 0.626          | 13.827         | 1640             |

Table 7. Results of sawdust cement mortar (treated sawdust)

| Sawdust % | w/c% | Compressive strength (N/mm\(^2\)) | Modulus of rupture (N/mm\(^2\)) | Absorption % | Density kg/m\(^3\) |
|-----------|------|-----------------------------------|-------------------------------|--------------|-------------------|
|           |      | 7 days age | 28 days age |                  |                  |
| 10        | 50   | 19.47    | 31.78    | 4.95           | 5.77           | 2080             |
| 20        | 55   | 18.05    | 21.98    | 5.23           | 5.81           | 2013             |
| 30        | 60   | 16.51    | 17.51    | 4.68           | 4.68           | 2000             |
| 40        | 65   | 11.45    | 14.0     | 0.55           | 8.51           | 1880             |
| 50        | 85   | 9.0      | 14.25    | 0.515          | 9.34           | 1850             |

Table 8. Results of sawdust cement mortar (treated and washed sawdust)

| Sawdust % | w/c% | Compressive strength (N/mm\(^2\)) | Modulus of rupture (N/mm\(^2\)) | Absorption % | Density kg/m\(^3\) |
|-----------|------|-----------------------------------|-------------------------------|--------------|-------------------|
|           |      | 7 days age | 28 days age |                  |                  |
| 10        | 50   | 21.6     | 35.2     | 4.45           | 6.28           | 2120             |
| 20        | 55   | 21.0     | 33.8     | 3.50           | 6.65           | 2000             |
| 30        | 60   | 10.7     | 23.9     | 2.64           | 9.71           | 1920             |
| 40        | 65   | 10.9     | 21.0     | 2.74           | 9.81           | 1910             |
| 50        | 85   | 10.2     | 20.9     | 2.79           | 11.5           | 1853             |

4. Conclusions and recommendations

1- Adding sawdust to cement mortar reduces compressive strength and flexural strength, however up to 50% addition cement mortar can be considered as lightweight cement mortar according to ACI Committee definition states that compressive strength of a structural lightweight concrete at 28 days should be higher than 15-17 (N/mm\(^2\)) and air dry unit weight of structural lightweight concrete should be lower than 1850 kg/m\(^3\) [15]. As shown in Tables 6-8 and Figures 5-7.
2- The increase in the proportion of sawdust in the mixture leads to increase water-cement ratio because part of water will be absorbed by sawdust, but the treatment of sawdust with hypochlorite solution causes a decrease in water-cement ratio compared with that of untreated sawdust as shown in Table 4.

3- The treatment of sawdust with hypochlorite solution in the first case (without washing) led to decrease compression strength as shown in Table 7 and Figures 5-7. This is due to the release of hydrochloric acid (HCl) which interacts with the components of cement and led to a decrease of compressive strength.

4- The sawdust treatment with hypochlorite and then washing it, led to increasing the compression strength of the mortar significantly compared with the untreated mortar and treated one without washing as explained in Table 8, and Figures 5 and 6.

5- Treatment of sawdust with hypochlorite led to great improvement in water absorption by mortar compared to untreated sawdust as explained in Tables 6-8 and Figure 9.

6- Adding sawdust to cement mortar prevents defragment of the mortar specimens when subjected to compressive loading, that mortar samples with sawdust keep their original shapes after failure compared to the original mix and the cracks are very thin in flexure as shown in Figure 10 and 11.

7- The uses of sawdust in cement mortar lead to recycling these materials in a more environmentally friendly manner.

8- The use of sawdust in cement mortar leads to an economic benefit by reducing cement demand; this has an economic effect in reducing the pressure on the consumption of construction materials and reducing the overall costs.

Figure 5. Compressive strength (7 days age).
Figure 6. Compressive strength (28 days age).

Figure 7. Modulus of Rupture (28 days age).

Figure 8. Density and sawdust percentage relationship.
Figure 9. Absorption and sawdust percentage relationship.

Figure 10. Lowest sawdust percentage

Figure 11. Higher sawdust percentage.

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