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Mechanical Properties of Concrete Partially Replaced with Sawdust as Fine Aggregate

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A B S T R A C T

This paper discusses the mechanical and durability properties of concrete with sawdust as a partial substitute of fine aggregate. Sawdust obtained at a wood workshop in Karbala was used as a replacement in concrete mixes of 0%, 5%, 10%, and 15%. The experimental program tested compressive strength, splitting tensile strength, and density at the age of 7 and 28 days of curing. It was found that 5% replacement of sawdust increased the compressive and tensile strength slightly relative to the control mix, whereas replacement levels of more than 5 % causes a progressive decrease in strength and density. These decreases are owed to the high porosity and low density due to the fibrous and lightweight nature of sawdust. However, a 10% replacement sustained favourable mechanical performance and offered economic and environmental benefits. The results indicate the viability of using small amounts of sawdust as a substitute of the conventional sand in concrete. The research proposes more research on mix design optimization and long-term performance of sawdust concrete in different environment conditions.

الخواص الميكانيكية للخرسانة المُستبدلة جزئيًا بنشارة الخشب كركام ناعم

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الكلمات المفتاحية:
الخرسانة الخضراء
المواد خفيفة الوزن
الخرسانة صديقة البيئة
الاستبدال الجزئي
نشارة الخشب

الملخص

يناقش هذا البحث الخصائص الميكانيكية والمتانة للخرسانة عند استخدام نشارة الخشب كبديل جزئي للرمل الناعم تم الحصول على نشارة الخشب من ورشة نجارة في كربلاء، وأُستخدمت بنسب استبدال في الخلطات الخرسانية بلغت 0%، 5%، 10%، و15.% شمل البرنامج التجريبي اختبارات مقاومة الانضغاط، مقاومة الشد الانشطاري، والكثافة عند أعمار 7 و28 يومًا من المعالجة. أظهرت النتائج أن استبدال الرمل بنسبة 5% بنشارة الخشب أدى إلى زيادة طفيفة في مقاومتي الانضغاط والشد مقارنة بالخلطة المرجعية، بينما أدى الاستبدال بنسب تتجاوز 5% إلى انخفاض تدريجي في كل من المقاومة والكثافة. يُعزى هذا الانخفاض إلى المسامية العالية والكثافة المنخفضة الناتجتين عن الطبيعة الليفية والخفيفة الوزن لنشارة الخشب. ومع ذلك، فقد أظهرت نسبة الاستبدال 10% أداءً ميكانيكيًا جيدًا، إضافة إلى فوائد اقتصادية وبيئية. تشير النتائج إلى إمكانية استخدام كميات محدودة من نشارة الخشب كبديل جزئي للرمل التقليدي في الخرسانة. ويقترح البحث إجراء دراسات إضافية لتحسين تصميم الخلطة ودراسة أداء الخرسانة المحتوية على نشارة الخشب في ظروف بيئية مختلفة على المدى الطويل.

1. Introduction

Engineered research is progressing very fast because there is growth in population as well as economic growth that generates further industrialization and urbanization on the territorial grounds. The efficient and sustainable enhancements are now in focus as far as the development of the construction industry is concerned [1], [2], [3].
The emergence of new technological innovations causes the traditional methods of construction to be replaced by high-tech product solutions. The new developments not only enhance performance in operations but also reduce traditional raw material requirements[4], [5], [6], [7], [8] . The wall panels of frame construction are mostly used to create boundary spaces to allow privacy and no longer must support loads. The walls need a material that must bear only its own weight therefore the developers can select light weight and low strength masonry material to reduce the dead loads. The construction industry of the entire world is developing [1]. Many residential and non-residential buildings are being constructed. The works in most building constructions comprise of concrete work, hence, the decrease in price of concrete manufacturing will decrease the price of construction [9]. A partial replacement of mix with the

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prospect of maintaining performance qualifications is an exciting prospect due to wider applications in concrete wall building. There has been some academic work on replacing sand with sawdust as fine aggregate in concrete because sawdust is a waste product of sawing and other related industrial activities [10]. Saw dust is an organically waste(products) of the mechanical milling or processing of timber (wood) into different shapes and forms sizes. The dust is normally utilized as household fuel. The form of resulted ash is called saw dust ash pozzolana [11]

Abdullahi et al. [12] experimented on concrete compressive strength by replacing sand content with sawdust in varying percentages up to 50 % According to the research results, replacing sand with sawdust in higher proportions led to a continuous decrease in compressive strength of concrete. A replacement level of ten percent sawdust was the optimum replacement level because higher replacement levels led to nonconformity with standard building requirements. This was caused by the strength reduction due to the presence of organic materials in the sawdust, which did not allow cement to hydrate normally and minimize its Strength development.

Jeson P. et al. [13] conduct a study of concrete material composed of silica powder as a cement substitute and sawdust ash (SDA) as a fine aggregate variation. A substitution of natural sand with SDA was performed at replacement levels of 5% to 10% to 15% in concrete specimens where tensile and compressive tests were conducted at 7, 14 and 28 days. The experiment showed improved compressive strength results when concrete used 5% SDA together with 25% silica powder to replace cement when compared to regular concrete. When SDA exceeded a 5% content level structural strength of concrete decreased because SDA maintains low bulk density values. Scientific records indicate that SDA delivers beneficial concrete performance results when its usage remains restricted.

Gopinath et al. [15] conduct an extensive study on the viability of using sawdust in cement mortar and cement concrete, in which sawdust was utilized as a partial replacement of fine aggregates (sand and silica). This research was conducted by completely substituting sand with dry sawdust (DSD) and sawdust ash (SDA) at replacement percentages of 0, 10, 30 and 50 %. The samples were subjected to compressive strength tests at the curing ages of 7, 21 and 28 days. Also, density and slump tests were carried out to determine the fresh and hardened parameters of the mixtures. The findings showed a steady increment of density as the content of sawdust increased. In particular, the DSD was found to be around 90 % less dense than the natural river sand, whereas SDA was 60 to 80 % less dense than Ordinary Portland Cement (OPC).

The compressive strength of the 1:5 mortar at 7-day was 92%, 77%, and 50% of the control strength at 10%, 30%, and 50% DSD replacement, respectively. Respective self-weight reductions were registered at 5, 10 and 15 %. The 28-day compressive strength of M20 grade concrete with a mix ratio of 1:1.5:3 went down to 80%, 75%, and 47% of the control at the same levels of DSD replacement. On the other hand, in concrete samples with SDA, the strength attained 91, 80 and 78 % of control strength at 10, 30 and 50 % replacement, respectively, after 28 days. The linked density decreases were 9, 16 and 23%.

Batt et al. [16] study the replacement of Ordinary Portland Cement (OPC) partially with wood ash and replacement of fine aggregate with foundry sand. Some of the performance parameters assessed in the study were flexural strength, compressive strength, split tensile strength, water absorption, soundness, carbonation, bulk density and drying shrinkage at the ages of 7, 28 and 56 days of curing.

The results indicated some interesting observations. The quality and composition of wood ash may differ considerably owing to combustion temperature, type of wood and burning time. Thus, it is important that wood ash should be thoroughly characterized before being put into practical use. The strength values especially compressive strength values, were higher than that required in M20 grade concrete, thus showing the replacement was successful.

Optimal replacement level of wood ash gave good results, and water absorption behavior was improved, and the mix became less prone to moisture penetration. Furthermore, the concrete had increased load-bearing capacity with increased ductility which minimized brittle failure. Addition of wood ash enhanced quality of cementitious paste that resulted to enormous split tensile and flexural strength development. In general, the research proved the wood ash could be a good and useful additional material in concrete manufacturing.

Prasanna et al. [17] determined the strength properties of concrete obtained by partial substitution of river sand with sawdust and Robosand through an experimental study. This research was done by testing the specific gravity, fineness modulus, moisture content, and bulk density of sawdust, river sand, and Robosand as well as the physical properties of cement and coarse aggregates. The compressive and tensile strength was carried out on the 7th and 28th day of curing. Further, cost analysis of M20 grade concrete mix with optimum replacement of 10 % sawdust and 40 % Robosand, making a total replacement of 50 % of fine aggregate was also done. The mix was found to save cost to the tune of Rs. 123.75 per cubic meter of concrete.

At 7 days the outcomes denoted that around 70 %of the target compressive strength was obtained. The compressive strength at 28-day gradually decreased when the replacement level of fine aggregate increased. Hence, partial replacement by sawdust and Robosand can be useful in the early strength gain and cost effectiveness, however not very useful when long-term strength is a paramount attribute.

Chandana et al. [18] examined the strength properties of concrete in which part of the fine aggregate was replaced by sawdust and Robosand. The experiment entailed an assessment of the physical qualities of sawdust, Robosand and river sand. Concrete mixes were made with 0, 25, 50, 75 and 100 %replacement of fine aggregate by 5 % sawdust + 20 percent Robosand, 10 %t sawdust + 40 % Robosand, 15 %sawdust + 60 % Robosand and 20 % sawdust + 80 % Robosand respectively. Mechanical performance of these mixes was determined through compressive strength and split tensile strength tests.The study also involved cost analysis. The findings revealed that the 28-day compressive and split tensile strengths deteriorated progressively as the percentages of replacement increased. The compressive strength was about 70 per cent of the 28-day characteristic strength at 7 days. Of all the mixes, the total replacement of 50 % (10 % sawdust and 40 % Robosand) was found to be the best mix to be used to obtain the M20 grade of concrete. This blend also meant a 7-percentage decrease in weight and about 85Rs. saving per cubic meter of concrete. The paper also indicates that the performance of concrete created using such alternative materials might be improved using appropriate admixtures to boost its strength characteristics. It further suggests that the fire and thermal resistance of sawdust concrete should be explored further to allow wider applicability of the material in practice.The advantage of sawdust in self-curing concrete is that the wood product keeps moisture using its fine wood particles. Laboratory studies indicate that sawdust can behave in the same manner as the conventional fine aggregates if they are utilized well without any adverse effects.

2. Materials

In this study, the concrete mixes were made with Sulphate Resistant Portland Cement Type V, coarse and fine aggregates, and sawdust as shown in Figure 1. The cement which is known as Al-JESR in the market, fits all the specifications in Iraqi Specification No. 5/2019[19]. The specific gravity of the fine aggregate collected in Al-Ukhaydir was 2.56 and that of the coarse aggregate made from crushed stone was 2.63. The Iraqi Specification No. 45/1984 was followed when both types of aggregates were tested mechanically and physically, showing them to be ready for use in concrete[20]. The properties of these aggregates are listed in Tables 1,2 and 3. Also, sawdust obtained from the workshop was added to the concrete to save on other materials. Table 4 shows that its specific gravity was calculated to be 1.2.

Table 1: Chemical and physical properties of the aggregate

The property	Aggregate type	
	Coarse aggregate	Fine aggregate
Specific gravity	2.63	2.56
Water absorption, %	0.22	0.78
SO_3, %	0.046	0.105

Table 2: Sieve analysis of fine aggregate

Sieve size mm	Passing %
10	100
4.75	90.8

2.36	76.75
1.18	64.65
0.6	29.6
0.3	6.8
0.15	5.8

Table 3: Sieve analysis of coarse aggregate

Sieve size mm	Passing %
19.5	98
9.5	35
4.75	1

Table 4: Physical properties of Saw Dust

Sieve size mm	Passing %
10	100
4.75	92.3
2.36	62.4
1.18	32.5
0.6	16.8
0.3	6.9
0.15	5.7
Specific Gravity	1.2
Fineness Modulus	2.13
Water Absorption	190%

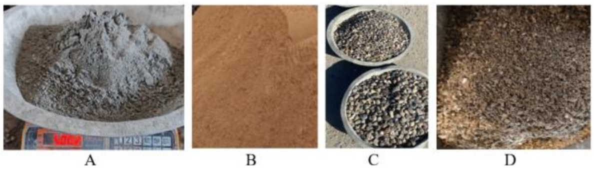

Fig.1: materials used (A cement, B sand , C gravel , D saw dust)

3. Experimental Investigation:

3.1. Mix proportion

To make sawdust concrete mix, sand and sawdust were first mixed without cement. The pre-mixed dry ingredients and coarse aggregate were added back into the mixture and five minutes more was allowed for thorough mixing with water. Five blends of concrete were tested using sawdust levels from 0% to 15%, to investigate how they affected the concrete's properties. Mix proportions and slump results for all mixes are shown in Table(5)[21].

Table 5: mix proportions

name	Concrete mix proportion	Water cement ratio	Slump (cm)
NC	1:2:2.54	0.45	8.5
5%SD	1:1:2.42	0.5	9.0
10%SD	1:1.15:2.42	0.55	9.5
15%SD	1:1.28:2.42	0.6	11.5

3.2 Casting and curing specimens

Casting and curing were standard procedures done on both cube specimen (100×100×100 mm) and cylindrical specimen (100×200 mm). Molds Steel molds of both types were lined with oil on the inner surfaces to avoid adhesion and molds were set on a flat platform. The weights of sawdust, sand, cement, and coarse aggregates needed were measured properly according to the type of specimen. Dry ingredients were mixed thoroughly and then a third of the total mixing water was added. In the case of the cylinders, a chemical admixture was dispersed in balanced water, and this was added into the mix to achieve homogeneity. The workability of each batch was checked by carrying out slump tests. The poured concrete was then placed in the molds in stages--three equal stages in the case of cubes, each stage being tamped with 25 blows of a tamping rod, and four equal stages in the case of cylinders, each stage being tamped with 35 blows per stage. A trowel was used to make the top surface of each specimen level as shown in figure 2. The molds were then de-molded carefully without disturbing the specimens and all the samples were then taken into a curing tank to ensure water curing.

Fig. 2: casting of specimens

4. Mechanical Tests

4.1 Compressive strength

Compressive strength of concrete was determined as per the British standards with the use of (100 *100* 100)mm cube molds [22]. The tests were performed at the curing ages of 7 and 28 days with the percentage of sawdust replacement the fine aggregate partial substitute. The outcomes proved that the compressive strength showed a non-linear pattern. Compressive strength gain was about 8.4 percent at a 5 % replacement level over control mix, and this implies an internal matrix structure or curing efficiency enhancement potential. But as the replacement level went up to 10 %, the compressive strength reduced by a small margin of approximately 1.5 %. Further increment to 15 % sawdust mix resulted in a further drop of about 4% as compared to 10 % sawdust mix. This reduction with the increased replacement level is mainly blamed on the rise in porosity and the decrease in density of the concrete which negatively influence the bearing capacity of the concrete.

Table 6: Compressive strength of specimens

Type of Mix	Compressive Strength Test (MPa)	
	7 days	28 days
NC	28	32
5%SD	30.3	34.7
10%SD	28.8	32.5
15%SD	27.4	31.2

The small variation in compressive strength between the 7-day and 28-day values across all mixes can be attributed to several factors. Firstly, the increase in porosity caused by partially replacing fine aggregate with sawdust may limit further hydration after the initial curing period. The hygroscopic and fibrous nature of sawdust tends to retain water in a localized area, enhancing early hydration but not contributing to later strength development. Additionally, the organic matter present in sawdust can somewhat impede the formation of calcium silicate hydrate (C-S-H) gel, resulting in a slower rate of strength gain compared to conventional concrete.

4.2 Tensile strength

The tensile strength of concrete is found by following ASTM C496/C496M[23], with cylindrical specimens that are 100 mm in diameter and 200 mm high. The test involves putting pressure along the vertical diameter of the sample using a compression testing machine. The loading setup creates nearly equal tension on the surface of the solid, but very strong compression occurs right where the load is applied. Every time the specimens have been in the curing tank long enough, they are taken out and left to dry so that their surfaces become saturated surface-dry (SSD). Every piece is placed so that it is vertically in the middle and between the two bearing strips, which are plywood or similar, to make the load even as it goes up the cylinder. Until failure happens, load is added continually and gradually as specified by the standard. The value of the greatest load handled by the specimen at rupture is taken and plugged into the formula to find the splitting tensile strength of the concrete.

The test results showed that there was a marginal increment of 4.8 % in splitting tensile strength when the replacement level of sawdust was 5 % in comparison to the control mix. But the tensile strength started reducing gradually as the replacement ratio rose as shown in table (7). At 10 and 15% replacement, the tensile strength was reduced by 1.6 and 4.8%, respectively, as compared to the control. This decrease in tensile strength may be ascribed to various factors but most significant among these factors is the compromised internal bonding and lesser cohesion within the cementitious matrix due to use of sawdust. Besides, their greater porosity due to the presence of sawdust facilitates early cracking when subjected to tensile forces. The decreased density of the concrete mix further leads to decreasing resistance to the longitudinal splitting, thus adversely impacting the tensile performance.

Table 7: Split Tensile strength of specimens

Type of Mix	Tensile Strength Test (MPa)
NC	3.1
5%SD	3.25
10%SD	3.05
15%SD	2.95

4.3 Density

The hardened concrete density was obtained based on BS EN 12390-7 [24]. They were made of 100 x 100 x 100 mm. The samples were cleaned to a saturated surface dry (SSD) condition after curing and weighed and the density was calculated as the mass divided by the cube volume. Experimental findings indicate a persistent reduction in the density of concrete as the percentage substitution of the fine aggregate with sawdust increases. The maximum densities were obtained at 0% replacement (control mix), of 2480 kg/m 3 after 7 days and 2510 kg/m 3 after 28 days, denoting a dense and compact concrete matrix characteristically of normal mixes.

With 5% sawdust, the density was reduced slightly to 2430 kg/m 3 after 7 days and 2490 kg/m 3 after 28 days. This decrease may not be much, but it is an impact of adding a lightweight organic substance like sawdust. The mixture still had a fairly good density indicating that a small proportion of sawdust can be incorporated without major change on the bulk density.

Further decrease in density to 2336 kg/m 3 at 7 days and 2425 kg/m 3 at 28 days was observed as the replacement level went to 10%. This is a more pronounced decrease, it being due to the lower specific gravity of sawdust and to its disposition to augment internal porosity. The increased porosity could probably be attributed to the fibrous and absorbent characteristic of sawdust that makes the hardened mix less compact.

The density decreased the most out of all mixes to 2292 kg/m 3 in 7 days and 2317 kg/m 3 at 28 days at the highest replacement level of 15%. This substantiates the fact that the content of sawdust exceeding an optimum level result in a significant loss in density, attributable to the light nature of the material in addition to the disturbing influence on the packing of aggregates and the homogeneity of the mix.

In all mixes, an overall density increment was noted between 7-28 days, probably because density decreased with time as hydration and refinement of the matrix proceeded. The density gain was however less at the higher sawdust contents indicating that the long-term densification process is impaired in the more porous mixes.

Finally, although replacement of sawdust up to 5 % can produce acceptable density reductions with little sacrifice in structure, replacement above 5 % can produce large density reductions and perhaps cannot be used in structural concrete without additional adaptation. Table 8 show the result of density for all mixes

Table 8 : Density of concrete specimens

mixes	Density kg/m 3	
	7 days	28 days
NC	2480	2510
5%SD	2430	2490
10% SD	2336	2425
15% SD	2292	2317

5. Extended Discussion

Water absorption capacity can significantly change when sawdust is added to concrete mixes due to the hygroscopic nature of wood particles. Sawdust has the potential to absorb and retain water, which can lead to an overall increase in water absorption in the composite material. This, in turn, may affect the durability and dimensional stability of the concrete under service conditions. Exposure to humid or marine environments, as well as submergence, can cause the individual wood particles to expand, potentially leading to microcracking and a decrease in structural integrity[25] [26].

Additionally, as an organic material, sawdust can become biologically unstable (such as rotting) if it remains in the presence of moisture for extended periods. Although the alkaline environment of cement paste can inhibit some microbial activity, prolonged wet conditions may still result in partial disintegration of the wood particles. These effects can be mitigated through preventive methods, such as adding chemicals to impregnate or coat the sawdust before mixing [27].

From an economic standpoint, sawdust can serve as a partial replacement for cement, which can lead to material savings, especially where sawdust is abundant as a waste by-product. However, the potential decrease in strength and durability must be considered, as it is a crucial factor when weighing these cost savings[28].

6. Conclusions

This research examined the possibility of using sawdust concrete mixture as a partial substitute of fine aggregate. Its impacts on strength, density, and the overall performance were also revealed, and both the possible field and the constraints were noted.

1- The use of sawdust as a partial substitute of fine aggregate affects the mechanical properties and density of concrete.
2- compressive and tensile strengths were slightly increased with a 5% replacement level.
3- When the replacement level exceeded 5 percent, strength and density decreased gradually because of both an increase in porosity and the low specific gravity of sawdust.
4- Even a 10% replacement by sawdust preserved decent mechanical properties.
5- A replacement of 15 per cent caused significant losses in strength and density but it still with the acceptable range for structural concrete.
6- A replacement level of 5 % is optimal, based on a balance between performance, sustainability and cost-effectiveness.
7- In certain applications, sawdust may be a renewable substitute to traditional sand, which contributes to the use of waste and decreases the burden on the environment.
8- It is also suggested that further research should be done to study long-term durability and perfect mix designs to be used in a wider construction industry.
9- The results indicate that the compressive and tensile strengths of the concrete were reduced when sawdust was used as an organic filler in the mixture. This reduction is expected due to the low density and mechanical strength of sawdust. However, future studies should focus more on important factors such as water absorption, volume stability, and durability under wet or submerged conditions, as these aspects are critical for real-life applications. Additionally, it is essential to conduct economic feasibility studies to assess the overall benefits of incorporating sawdust into concrete production. Therefore, it is recommended to explore pre-treatment methods for sawdust to enhance durability and to evaluate its long-term performance for large-scale applications.

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