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Orginal Article

Application of sawdust concrete in construction

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Abstract: Sawdust concrete is a type of lightweight concrete in which some of the mineral aggregate is replaced by sawdust – a by-product of wood processing. It is not a new material, but its potential is not utilised to its full degree. Taking into account the most important advantages of sawdust concrete – lower density and greater thermal and acoustic insulation than ordinary concrete – it is worth to consider the possibilities of its usage in construction wider than currently. In order to present the properties of sawdust concrete, the review of contemporary technical literature has been performed.

For the production of sawdust concretes mineralized sawdust from various types of trees, ordinary cements, mineral aggregates and water, are used. The usage of additives and admixtures is also allowed. The properties of the finished sawdust concrete are mainly influenced by the proportion of its components, especially the amount of fine aggregates replaced by sawdust. The construction products made of sawdust concrete are characterized by a low coefficient of thermal conductivity λ and soundproofing properties. In bending tests, a simply supported sawdust concrete beam behaves similar to a regular concrete beam, cracks first appear in the tension zone. Tensile strength, compressive strength and Young's modulus of sawdust concrete products depend on the proportion of components and the method of sawdust preparation before applying in the sawdust concrete-mix. Compared to ordinary concrete, the obtained values for sawdust concrete are lower, but partially fall within the ranges for the lower classes of ordinary concrete.

There are several possible applications of sawdust concrete in construction. One of the perspectives is to use it to build walls in buildings that require soundproofing between rooms, or to replace wood with it when renovating old buildings. However, further tests of sawdust concrete are needed in terms of the most favourable composition for its mechanical properties, and to define the standards according to which sawdust concrete elements should be produced.

Keywords: concrete, sawdust, sawdust concrete, construction, green building

1. Introduction

1.1. Principles of sawdust concrete

Intensive construction activity involves the use of large amounts of materials, especially those of natural origin, such as aggregates, and the production of tons of waste. The construction industry is responsible for about 25% of global greenhouse gas emissions [1]. Therefore, one of the challenges facing the construction industry should be to reduce its harmful impact on the environment and to use the available materials more efficiently.

A material which can respond to such needs is sawdust concrete – a type of lightweight concrete wherein sawdust replaces part of the traditional aggregates [2], [3]. It is not a new material, however, it is not as popular as it could be due to its ecological potential.

The sawdust used for production of the sawdust concrete is a by-product of carpentry processing. Their use for production of the concrete allows to reduce the consumption of natural aggregate and reduces CO_2 emissions. The big advantage of sawdust is its low price and easy availability, thanks to which the use of this material for production of the concrete does not generate additional logistical problems or costs. This is an advantage of sawdust over mineral aggregates – the latter with a constantly growing price and a limited area of extraction, which results in high transportation costs [1], [4].

This paper presents the characteristics of sawdust concrete and its components, as well as a description of its properties, in comparison to regular concrete grades.

1.2. Sawdust

More than 20 million m^3 of sawdust are produced annually in the world, most of which is incinerated. This leads to an increase in air pollution and greenhouse gas emissions [5]. Effective use of that raw material, e.g. for production of composite materials, is in line with ecological considerations. It would also contribute to savings in materials and costs of construction projects [3], [5]. The summary cost presentation of obtaining 1 m^3 of sawdust, gravel and sand is presented in Table 1 [6]. The presented table shows that the chips contribute to a multiple reduction in carbon dioxide emissions, and their transport uses about 7 times less energy – compared to sand and gravel.

Table 1. Summary of CO_2 emission and energy used for the transport of concrete components. *Source*: [6]

Material	Sawdust	Gravel	Sand
CO_2 emission [t/1 m^3 of the material]	0.0007	0.012	0.009
Energy used [GJ/1 m^3 of the material]	0.0195	0.148	0.134

The bulk density of sawdust, depending on its structure and the type of wood it comes from, ranges from about 160 to about 260 kg/m^3.

Fig. 1. Beech wood sawdust. *Source:* [7]

The available literature does not specify which types of wood are used to obtain sawdust with the best results as a material for the production of sawdust concrete. The available research shows use of chips from – for example – juniper, beech (Fig. 1), spruce, pine, fir and padauk trees [1], [3], [8]-[11]. Authors of mentioned papers used local species obtained from nearby sawmills and other wood processing centres.

Fig. 2. Fine sawdust. *Source:* [12]

Similarly to the types of wood from which sawdust is obtained, the recommended sizes of sawdust are not specified. Usually, the research uses sawdust with the largest size in the range 0.1 – 8 mm [3], [8]. It is also suggested to use a smaller maximum dimension of 5 mm [1], [10] or, on the contrary, up to 10 mm [11]. Another approach is to take the largest size of the sawdust as close as possible to that of the aggregate it is replacing. In the case of tests where fine sawdust (Fig. 2) replaces some of the fine sand, chips with a maximum dimension of 2 mm were used – to make the size of the wood particles as close as possible to the diameter of the sand grains [5].

Sawdust is an organic material, which means that special attention should be paid to protecting them against rotting and decaying. It was determined that the content of organic particles did not make the material susceptible to fungus [13]. However, it is also necessary to use certain substances to minimize the destruction of sawdust and the impact of other concrete components on them, through their mineralization [14]. Such preparation of sawdust reduces the strength drop of sawdust concrete [2].

There are various terms for small wooden particles, e.g. sawdust, shavings, wood dust, presented in literature. However, no standard name distinctions are given with regard to the size of the wood particles. For this reason, this article will not devote any space to linguistic discussion, and different names for the wooden filler will be used alternately.

1.3. Sawdust concrete

Sawdust concrete is a type of lightweight concrete in which sawdust replaces part of the traditional aggregate [2], [3]. An example of sawdust concrete block is shown in Fig. 3.

Portland cement plays the role of a binder [14]. It is possible to add additives and admixtures to sawdust concrete. As a result of the combination of wood and concrete, a material with a lower density and greater thermal and acoustic insulation than regular concrete is obtained [13], [15].

Fig. 3. Sawdust concrete block with 5% fine sawdust. *Source:* [16]

Due to different physical and chemical properties, direct connections between concrete and wooden elements are not used in construction. However, with proper preparation and combination of these materials, sawdust concrete is obtained, which is suitable for use in construction. Protected, e.g. by mineralization, the sawdust does not exhibit the negative properties of wood, e.g. they do not decompose, do not rot and do not have high water absorption. Mineralized sawdust does not hinder the cement setting process and the production of sawdust concrete itself does not differ significantly from the production of regular concrete. It is worth noting that the addition of sawdust does not affect the homogeneity of the concrete mix [3].

As the sawdust content increases, the mechanical properties of sawdust concrete deteriorate. This is because the strength of the material decreases as compared to regular concrete [2], [3]. Studies have shown that the durability and strength of sawdust depends on the texture, size and angularity of the wood particles [1]. Thus, it is only suitable for construction elements to a limited extent. However, it is worth noting that not all potential uses of sawdust in construction require high strength parameters.

When sawdust is mixed with cement and water, the organic material may begin to soak up with water, thus disturbing the water-cement ratio and reducing the amount of water available for the cement hydration process [9]. As the water absorption of sawdust increases, the material's freeze thaw durability decreases [1]. Unprepared, e.g. by mineralization, the shavings also slow down the hydration and hardening process of the mortar [4], [10]. Therefore, it is important to mineralize the sawdust before applying it to concrete. On the other hand, researchers noted the advantage of using non-mineralized sawdust. The water taken over by them during the mixing of the mortar later helps in the cement hydration process in places where it is not possible to add water during setting, for example in the middle of the poured layer [2], [4]. The tests performed for sawdust concrete samples with the use of 3-8 mm size sawdust have shown that the organic filler reduces capillary absorption inside the material [9].

2. Production of sawdust concrete

2.1. Ingredients

2.1.1. Organic material – sawdust preparation

Fig. 4. Fine sawdust before (left) and after (right) drenching it in a protective mixture made of cement and water. *Source:* [3]

Chips used for production of sawdust concrete need to be mineralized. Calcium chloride is used for this purpose – thanks to the supersaturation of natural wooden aggregate, it is protected against quick deterioration [13]. Chromated copper arsenate (CCA) is another substance used to protect sawdust [11]. Some sources suggest treating sawdust with broadly understood alkali [5]. Another approach proposed by some researchers is, in order to improve the adhesion between the cement and sawdust, placing the chips in a sodium silicate solution (100g/1l) 24 hours before mixing with other sawdust concrete components [9]. Also, protection of sawdust by prior coating it in a water-cement mixture (Fig. 4) in the cement-to-wood mass ratio of 2.5, results in increased strength and reduced shrinkage when setting concrete [3].

2.1.2. Cement

According to published research results, the CEM I and CEM II are the cements used for production of sawdust concrete [1]-[6]. However, it is not specified which cement is best for sawdust concrete, in terms of various factors, e.g. durability, strength. The use of these mixtures proves that known and common materials are selected for production, and that sawdust concrete does not require special cements.

2.1.3. Aggregate

Recipes for sawdust concrete vary depending on the research centre. They all share the use of fine sand, most often river sand [2] with a diameter of up to 5 mm [8]. It is an important component of sawdust concrete in terms of the proportion of components, because most often the amount of added sawdust is determined in relation to the amount of fine sand [2], [5], [11], [17]. Coarse aggregate [8] with an exemplary grain size of up to 9.5 mm [2] is also added to sawdust concrete. Granite aggregate can be used for the production of sawdust concrete [4], [5], however, in most research descriptions, the rock species from which the aggregate was obtained were not specified.

2.1.4. Additives and admixtures

Admixtures can be used to improve the properties of the mixture and the finished sawdust concrete, mainly to regulate the consistency and fluidity of the mixture, e.g. air entraining admixtures or stabilizers [10]. Some researchers have successfully added a superplasticizer to the mixture for sawdust concrete production [3], [8]. Successful trials of using additives and admixtures other than woodchips in sawdust concrete in laboratory tests prove that their use in sawdust concrete mixtures is right and safe.

Due to the fact that sawdust concrete has worse mechanical properties than regular concrete, the influence of other substances on the properties of sawdust concrete is also tested. It was verified that the addition of pozzolana in the amount of 10% increases the compressive and tensile strength of concrete. It is also important to note that the mentioned additive increases the durability of sawdust concrete [18].

2.2. Production of sawdust concrete

2.2.1. Ingredients proportions

The proportions of the ingredients are important to obtain the desired properties of the final material. The number of available studies on the determination of the quantity of aggregate that should be replaced with sawdust, favourable for the various properties of sawdust concrete, is small. Researchers do not agree on this point. The most common values in the studies are 5-30% [5], [11]. These are the proportions, according to recommendation, by volume [17]. However, the limit values have not been clearly defined – due to the insulating properties of sawdust on the one hand and the strength parameters of the resulting sawdust concrete on the other.

Usually, the water-cement ratio in sawdust concrete ranges from 0.4 to even 1.2 [17]. Examples of cement/sawdust/water ratios are: 1/0.46/0.7 and 1/0.22/0.7 [3], 1/0.27/0.75 [9], 1/0.16/0.61 [10]. Also mixtures with more sawdust were used for the tests – the cement to sawdust ratio was 0.67 [17] or even 0.81 [1]. Another proportion of the proportion of concrete solids, which is repeated in studies on sawdust concrete, is 1/2/4 (cement/sand/granite aggregate) [4], [5]. These discrepancies testify to the constant search for the best proportions of ingredients for the properties of sawdust concrete.

2.2.2. Manufacturing method

The production technology of sawdust concrete and preparation of samples made from this material is very similar to technology used for regular concrete. The first step for production of the sawdust concrete is the accurate weighing of all ingredients – initially in separate containers. Then the coarse and fine aggregate and cement are mixed together. Then sawdust is added and mixed again. Only then is water gradually added while stirring. The production scheme for sawdust concrete mix is shown in Fig. 5.

Another approach is to mix the sand with the sawdust first. Then add cement and mix again, then add coarse aggregate and mix again. Add water to all mixed dry ingredients in accordance with the adopted proportion [2]. It should be borne in mind that the water necessary for the recipe is the water needed by the concrete mix and the water that will be absorbed by the sawdust [19]. The latter amount has not been presented in the available literature so far. However, it is clear that the amount of water depends on the type of sawdust used.

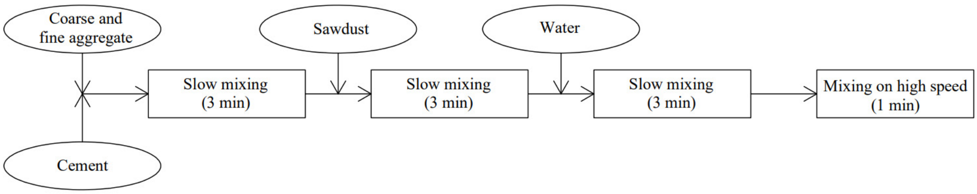

Fig. 5. Diagram of sawdust concrete mix formation. *Source:* [1]

For drying of cast sawdust concrete elements, conditions similar to those for regular concrete are assumed. However, it is not specified whether this affects the properties of the finished sawdust concrete or whether it was just considered appropriate to base on known conditions.

After casting, the sawdust concrete blocks can also rest in conditions of high relative humidity, reaching 90-97%, for the first 1 to 7 days. Later the humidity is lowered to 50%. The ambient temperature should be 20°C [3], [9].

Due to the reliable comparison of test results with elements made of regular concrete, elements made of sawdust concrete are also tested on strength machines after 28 days [3], [10], [17].

3. Properties of construction elements made of sawdust concrete

3.1. Physical properties

Density is a feature that translates directly into the weight of the finished element. The density of sawdust concrete decreases with an increase in the percentage of fine aggregate replaced by organic material [2], [3]. The exact value depends on the ratio of components and is in the range of 760-1880 kg/m^3 [5], [9], [10]. This allows the material to be classified as lightweight concrete, because its density does not exceed 2000 kg/m^3.

Air content in sawdust concrete depends on the sawdust percentage. This issue has not been well studied yet, however according to [20] the more sawdust used, the higher the air content and its value is in the range of 5.5%-14%.

One of the technically significant benefits of sawdust concrete is its low thermal conductivity coefficient λ (W/(mK)). Its value, depending on the sawdust content, ranges from 0.2 to 1.0 [3], [10], [13]. For comparison, the value of λ for regular concrete is up to 1.7, so the use of sawdust concrete can increase the thermal insulation of the wall.

Sawdust concrete also has sound-absorbing properties. Elements made of this material can be used as a good acoustic insulation due to the ability of sawdust concrete to extinguish sound waves [1], [9], [13].

Sawdust also reduces the electrical resistance of sawdust concrete – it is lower compared to regular concrete [18].

It is indicated that fire may cause a reduction in the volume of the concrete sample or a change of its colour to a darker shade [11], [21]. Since the fire resistance of sawdust concrete has not been well studied so far, it should not be recommended to apply sawdust concrete for fire-rated walls.

3.2. Water absorption

Water absorption is defined as the ratio of the difference between the mass of a material fully saturated with water and a material in a dry state to the mass of a material in a dry state, expressed as a percentage. The aim is to minimize water absorption, because the presence of water in the pores of the concrete negatively affects its properties. The measured water absorption of sawdust concrete was 29.7% [1], some the results were also below 20% [2]. The values, however, vary depending on how the sawdust was treated prior to mixing with the cement. Nonetheless, there are no studies that could clearly determine the relationship between the method of sawdust preparation and the absorbability of sawdust concrete.

Still, it is importantfor the obtained water absorption values to be below the limit value of 30%, above which the material would suffer deformations as a result of freezing and thawing water [22]. This allows us to argue that this parameter does not prevent the use of sawdust concrete for the construction of internal and external walls of buildings.

3.3. Mechanical properties

The most important mechanical properties in terms of use in construction are: compressive strength, flexural strength and Young's modulus. Determination of the ranges within which the expected and obtainable mechanical properties for sawdust concrete are important for the possibility of subsequent calculation of elements made of this material.

The compressive strength of sawdust concrete is measured, just like regular concrete, on cubes with dimensions of 0.1x0.1x0.1 m, after 28 days. The results obtained from the research are in a wide range, from about 5 to even 46.4 MPa [3], [9], [17], [23]. The discrepancies in the results occurred due to different proportions of sawdust concrete components, the mineral aggregate and class of the cement used and the conditions in which the samples dried. It was verified that too high humidity in a room with sawdust concrete elements resulted in a decrease in compressive strength with time [9].

The relationship between flexural (f_b) and compressive (f'_c) strength in sawdust concrete depends on the amount of aggregate replaced with sawdust and the class of concrete used. The ratio between those two strengths f_b/f'_c varies between 0.07 and 0.17 based on the research available [11], [17], [20].

In bending tests of simply supported sawdust concrete beams, they behave similarly to regular concrete beams – cracks first appear in the tension zone [1]. The tensile strength of sawdust concrete, determined in such tests, is in the range of 1.9 – 6.4 MPa [2], [10], [17].

The Young's modulus E for sawdust concrete determined in the research ranges from about 7 to 20 GPa [2], [17]. The obtained values depended on the water-cement ratios of the mixture and the amount of fine sand replaced with sawdust. A greater reduction of Young's modulus could also be influenced by an inappropriate proportion of sawdust concrete components – in the same tests for a mixture without sawdust, depending on the water-cement ratio (0.37-0.57), Young's modulus in the range of 15.23-22 was obtained [2].

It is possible to compare the obtained values to those given for concrete according to PN-EN-1992. Depending on the class of concrete, the characteristic cube compressive strength ranges from 15 to 60 MPa, therefore some values obtained for sawdust concrete fall within this range. The obtained values of Young's modulus for sawdust concrete are much lower than the European standards for concrete, for which, depending on the class, the modulus of elasticity ranges from 27 to 37 GPa. However, it should be noted that for sand aggregates, which were partially used in the tested sawdust concrete, the Young's modulus of concrete decreases by 30%, which gives the range of 18.9 – 25.9 GPa, which already includes some of the results obtained for sawdust concrete.

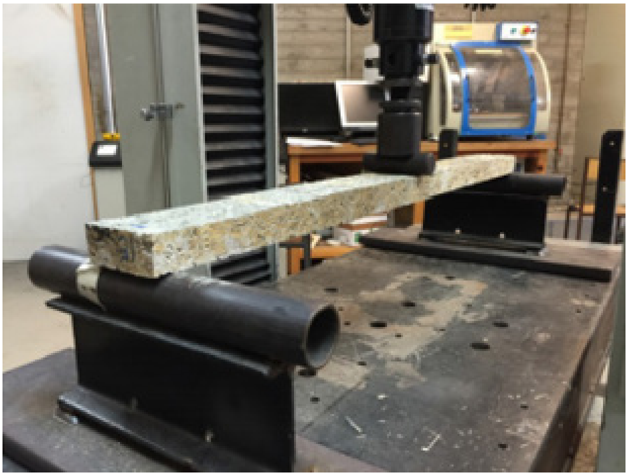

Fig. 6. Bending test of a simply supported beam made of sawdust concrete. *Source:* [1]

In order to better illustrate the tensile strength of sawdust concrete, in Table 2. the tensile strength σ (MPa) maximum values of the P force (kN) that can be loaded on a beam made of various materials in the bending test of a simply supported beam are listed (Fig. 6.). The calculations were made for a beam of 0.04x0.1m section and length l=1.0m, for which the bending index $W = 6.67 \cdot 10^{-9}$ (m³). The maximum value of the force P (kN) was calculated from the Eqs 1-3:

$$\sigma = \frac{M}{W} \tag{1}$$

$$M = \frac{Pl}{4} \tag{2}$$

$$P = \frac{4\sigma W}{l} \tag{3}$$

The summary clearly shows that sawdust concrete has lower tensile strength than metals, glass and even wood. However, the value of the maximum loading force P (kN) is greater than for concrete of the C20/25 class. There has been too little research investigating the potential improvement of the mechanical properties of sawdust concrete compared to concrete to draw far-reaching conclusions. It shows, however, that sawdust concrete does not have any strength properties inferior to the currently used building materials.

Table 2. Summary of the tensile strength and the maximum value of the force loading the beam. *Source: own study*

Material	Steel	Aluminum alloy	Glass	Concrete C20/25	Wood	Sawdust concrete (averaged)
Tensile strength (MPa)	540	215	30	2.6	87	4.15
P_{max} (kN)	144	57.33	8	0.69	23.20	1.11

Replacing some of the aggregate with sawdust does not change the failure pattern of concrete cylinders under compression [20]. The mechanism of sawdust concrete failure during bending is similar to regular concrete test. The effect of failure first occurs in the tension zone [1].

4. Application of sawdust concrete

4.1. Use in construction

Sawdust concrete is suitable for the production of prefabricated elements. It is not recommended to use it in structural elements [16]. Internal walls and ceiling panels can be made of sawdust concrete. Water absorption below 30% allows it to be used also for external walls, which are even exposed to negative temperatures [1].

Due to the lower value of the thermal conductivity coefficient than in regular concrete, it is possible to produce elements of thermal insulation layers [5], [9]. Due to the greater stiffness as well as acoustic and fire resistance compared to wooden elements, sawdust concrete can be used as a substitute for wood in the renovation of older buildings [7]. Thanks to its sound-absorbing properties, sawdust concrete can be used in elements that would simultaneously have a barrier and soundproofing function, e.g. as partition walls in cinemas, theatres or music schools.

It is important to note that sawdust concrete can be processed with tools whose primary application is wood processing [13]. This allows blocks to be processed quickly with commonly used and readily available equipment. This is especially important at a construction site when it is necessary to cut the block, e.g. in case of dimensional inconsistencies, unevenness or in order to obtain an equalizing block.

4.2. Other perspectives

Attempts were made to create composites of wood and sawdust concrete. Slabs made of such a composite, glued with epoxy or polyurethane, met the requirements for stiffness and flexural strength [7].

Elements made of sawdust concrete can be produced by 3D printing. The workability and lightness of the mixture are the positive features of sawdust concrete used in this technique, thanks to which sawdust concrete performs better than regular mineral mixtures. Elements made of sawdust concrete were made more precisely and with greater ease than those made of regular concrete mix [10].

5. Conclusions

Sawdust concrete is one of the "green building" materials, and its use allows for the reduction of construction costs. Taking into account the widespread interest in reducing the amount of waste from the construction industry and concern for the development of environmentally friendly technologies, the use of sawdust for production of the concrete can be considered a rational solution. In addition, the cost of producing sawdust is lower than mineral aggregate, shavings are also more easily available. This reduces the emissions and costs of production and transport of the material for the production of concrete.

Mechanical properties of sawdust concrete do not differ significantly from those of concrete of lower strength classes. The conclusions drawn from the research prove that obtaining the highest possible values of strength parameters will be possible when the most favourable proportion of components, the type of aggregate and the method of sawdust preparation are determined in terms of the impact on the mechanical properties of sawdust concrete.

The advantage of sawdust concrete is its acoustic and thermal insulation properties higher than for regular concrete. It creates many perspectives for using that material in insulation layers for various objects. For example: in partition walls of residential buildings, theatres, cinemas and as an insulating base in floors.

It was also found that sawdust concrete is a material liked by animals. Currently, birdhouses are made of this material. One of the prospects for the future is the use of sawdust concrete in livestock facilities.

In the world of construction, where various standards are omnipresent, guidelines for its production and use are necessary for the effective introduction of a new material on a large scale. For the further development and application of sawdust concrete technology, it is necessary to determine the recommended ratios of components and, in particular, the percentage of sawdust. It is also necessary to define the conditions to be met by sawdust so that the produced sawdust concrete is safe for use in the structure and durable. There is also a clear lack of standards defining the target ranges in which the values of various quantities characterizing sawdust concrete, such as: density, compressive strength, water absorption, should fall.

Due to the fact that sawdust is an organic material, it is necessary to take a closer look at the durability of sawdust concrete over a longer period of time. It is also recommended to further investigate potential changes in strength characteristics with time.

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