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Use of Agricultural Products and Waste in the Building Materials Industry

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Abstract

In the current context of industrialization, demographic explosion and accelerated development on all continents, the maintenance and improvement of life conditions require particular attention for ecology and environmental protection worldwide. This is why researches in all activity areas are currently focused on identifying strategies aimed at protecting natural resources that are running out, at reducing water, air and soil pollution, at using new renewable energy sources. The building sector, has a major environmental impact due to the resulting waste, occupation of land, air pollution and influence of biodiversity. The paper provides some examples of the way in which agricultural waste and natural products can be used in the building materials industry, with beneficial consequences for environmental protection and the preservation of natural resources. Thus, various thermal insulating materials derived from agricultural products and waste are presented, with their advantages compared to conventional thermal insulating materials. Another direction is the use of waste resulting from the processing of natural products or agricultural waste in concrete industry. The substitutes for aggregates used for the production of concrete contribute to the reduction of environmental pollution as well as to the protection of natural resources. On the other hand, rice hulls may partially replace Portland cement, whose production requires a great amount of energy. Another building material that has raised the interest of constructors is straw bales. The paper presents this building material considered from the point of view of the quality characteristics that straw should meet, the way in which bales are produced and the straw bale building systems.

Keywords: agricultural waste, building materials, thermal insulating materials, concrete, straw bales.

1. Introduction

The maintenance and improvement of living conditions requires a particular focus on ecology and environmental protection worldwide. This is why research in all activity areas is aimed at identifying new strategies and means for solving energy and environmental problems.

The construction sector has a major environmental impact due to resulting waste, occupation of land, air pollution and influence on biodiversity. This requires new approaches in the construction of buildings and the manufacture of building materials.

The use of waste for the manufacture of building materials is an effective way to reduce the consumption of material resources and at the same time, to significantly reduce the negative environmental impact.

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Agriculture is the sector responsible for the production of plant and animal food, fibers and various useful materials, and it can be an important source of raw materials for different industrial sectors, including construction. In the field of construction, agricultural products and waste resulting from their processing may be important raw material sources for the manufacture of ecological building materials.

2. Thermal insulating materials using agricultural waste and natural products

From an ecological point of view, thermal insulating materials are high energy consumers. Their high embodied energy is compensated by the advantage that by their use in construction, the required operational energy is significantly reduced. The saved energy contributes to the reduction of polluting environmental factors.

Thermal insulating materials based on agricultural products and waste have a clear advantage over traditional thermal insulating materials due to the low embodied energy.

2.1 Hemp

Hemp, one of the oldest cultivated plants, has an important contribution to the supply of mankind with sufficient amounts of clothes, paper, oil, fuel, food. Hemp can reach 4 meters in height in a period of 100-120 days.

In construction, hemp is used as insulating mattresses of various sizes that are easy to handle and install (fig. 1).

The product is recommended for the insulation of roofs, walls and floors, having a thermal conductivity coefficient $\lambda \approx 0.040$ W/m K [10]. The good diffusion capacity of the product ensures the automatic regulation of humidity, which allows for pleasant and healthy indoor climatic conditions.

Figure 1. Hemp mattresses for thermal insulation [10]

Due to the fact that hemp fibers do not contain albumin, no treatment against moths and beetles is necessary.

Whether insulation is intended for new or old buildings, the installation of the insulation poses no problems for users. Clean, almost dust-free processing, good skin tolerance without the presence of irritations, as well as good insulation values, make this product a good building material. Protection against freezing during winter and adequate protection against high temperatures during summer months is ensured.

2.2 Flax

In Romania, flax is a plant grown on relatively large surface areas for fibers or oleaginous seeds. Flax grown for fibers is taller and less ramified than flax grown for oil.

In construction, flax can be used as felt or plates made from flax fibers (74%) mixed with polystyrene fibers (18%), impregnated with ammonium sulfate (8%). Flax insulation has a low embodied energy compared to other insulating materials (30 kWh/m^3) [2].

The product is recommended for ”breathing” buildings, in areas without high static strains, having a thermal conductivity coefficient $\lambda \approx 0.4 - 0.5$ W/mK [2].

2.3 Reed

Due to its physical properties, reed is a good building material, being light and stable at the same time. Air in and between the reed stems ensures particularly good thermal and sound insulation, providing in this way a high degree of comfort.

Reed is mechanically pressed and bound with galvanized metal wire. Reed plates may be of various sizes and qualities.

A reed plate is a classic insulation material that can be used for both indoor and outdoor insulation or for roof insulation.

The thermal conductivity of reed insulation is λ=0.09 W/m K [3].

For improving fire resistance, reed plates should be made fireproof. A particular problem is metal wire (used to bind the reed stems), because this makes the adjustment of the plate sizes difficult. This is why alternative modalities for binding the reed have been tested, which involve the use of certain binders, additional compounds or new fixation techniques (figs. 2a-d) [9].

In order to bind the reed stems together, cellulose flakes (fig. 2a) and natural resin glue (fig. 2b) are used. By covering the reed with a special maize binder that can also be used as a hot binder, the direct gluing of the reed stems is obtained (fig. 2c). By filling the spaces between the reed stems with a natural lime mortar, a resistant but very heavy plate is obtained (fig. 2d).

On the other hand, this plate has an extremely high sound insulation effect.

Figure 2a. Reed plates with a cellulose flake binder

Figure 2b. Reed plates with a natural resin glue binder

Figure 2c. Reed plates with a maize binder

Figure 2d. Reed plates with a lime mortar binder

2.4 Expanded cork

Cork is a natural material obtained from the cork oak. Cork boards are products obtained through the natural agglomeration of granules in their own resin and can be used in any environment and climate conditions.

The expanded cork board is a material with very good thermal insulating and acoustic properties (fig. 3).

It is stable during stretching and compression (elastic), antibacterial (not allowing for the development of fungi, mold), antiallergenic, fire resistant, durable and it does not absorb water through capillarity.

Figure 3. Cork boards [7]

The density of expanded cork boards is 110-120 kg/m³, and their thermal conductivity coefficient is 0.037 – 0.040 W/m K [7].

2.5 Natural wool

Natural wool can be used like glass wool or basalt wool in the form of insulating layers or rolls, as a thermal insulating material (fig. 4). The product can be used for ”breathing” buildings, in areas without high mechanical strains.

Figure 4. Wool thermal insulation [6]

Wool insulation has a thermal conductivity coefficient λ ≈ 0.039 W/mK and low embodied energy (145 kWh/m^3) [6].

The thermal insulating properties of wool are maintained even in a wet state. Through the rapid absorption and release of humidity, it attenuates extreme temperature variations, for example in house roofing.

3. The use of agricultural waste in concrete industry

Concrete occupies a particularly important place in the construction industry, being used frequently and in high amounts, but its production has negative environmental effects, starting with the extraction of raw materials and finishing with its high embodied energy. This has led specialists to search new solutions of recipes and technologies for the manufacture of concrete.

The study is aimed at finding new solutions for reducing the use of natural resources (reuse of waste), as well as fossil fuels, through the wide use of alternative energy sources.

3.1 Aggregate substitutes

Some natural products and waste resulting from the primary processing of agricultural products may be used for the manufacture of ecological concrete as aggregate substitutes.

Sawdust is abundantly available and is used for the manufacture of light concrete, subjected to moderate strain. Sawdust contains considerable amounts of water soluble impurities that delay the hydration and setting of the cement paste. In order to neutralize sawdust impurities, physico-chemical treatments are necessary, which considerably increase the price of concrete.

In order to make sure that auxiliary sawdust materials will not affect the setting of concrete, sawdust can be pretreated by water soaking and washing before mixing, with the addition of calcium oxide or a magnesium oxide and dolomite powder mixture [2].

Rice husks can be used as an aggregate for the production of concrete blocks and prefabricated elements for floors.

The rice husk contains a relatively small amount of water soluble impurities compared to sawdust and has a low bulk density, 100 – 150 kg/m^3. The apparent density of rice husk concrete is about 600 kg/m^3 or higher, depending on the proportion of husks, cement and the degree of compaction. Compressive strength is between 3 and 12 N/mm^2 [2].

Coconut kernel [2] is waste in the form of granules and dust resulting from the separation of the coconut fruit from the husk. In this way, large amounts of kernel are obtained, which can be used as a light aggregate in concrete. Storage in a wet state destroys the active ingredients from the kernel by solubilization and bacterial action. The melted kernel obtained as waste in coconut fiber industry has a mild reactivity with Portland cement.

The bulk density of coconut kernel granules ranges between 80 and 90 kg/m^3 and the resulting concrete has densities ranging between 432 and 768 kg/m^3. The concrete obtained using coconut kernel has a low thermal conductivity, varying between 0.052 and 0.110 W/mK, which makes it adequate for thermal insulation. The small fissures resulting in concrete prepared in this way, due to contraction during drying, can be repaired without significantly affecting its thermal insulating properties.

Cork granules resulting from packages can be used to produce light concrete. Depending on the proportion of cement and the amount of cork granules, compressive strengths varying between 4.2 and 12.0 N/mm^2 for an apparent density of 475 up to 890 kg/m^3 were obtained [2].

Cork granule concrete can be used to replace earth fillings above buried pipes, for embankments adjacent to water retention constructions, sound proofing screens, etc.

3.2 Portland cement substitutes – rice husk ash

The reduction of Portland cement production would result in a significant reduction of greenhouse gas emissions.

The waste used as cement replacement additions consists of minerals in the form of fine powder derived from other production processes. In combination with water, these have the property to set and harden very slowly, which is significantly accelerated by the presence of cement. As cementitious additions, besides power station ash and some types of blast furnace slag, rice husk ash can also be successfully used.

Rice husk ash can partially replace Portland cement in the composition of concrete. 85% up to 97% of rice husk ash is amorphous silicon, whose reactivity depends on the burning process used. The quality of the rice husk ash depends on the burning temperature, the duration of burning, the air supply requirement during burning, the cooling rate of the resulting hot ash, and the grinding time [2].

From a cement mixture containing 20% rice husk ash and 80% cement, a mortar with a compressive strength of 61.3 N/mm^2 at 28 days was produced, compared to 43.6 N/mm^2 for standard mortar, without rice husk ash addition. Interestingly, even when the mixture contained up to 70% rice husk ash, the mortar produced was more resistant than standard mortar, regardless of duration[2].

4. Straw bales used in construction

Walls made from straw bales stacked and plastered on both sides with earth or with cement or lime mortars may take relatively high loads and meet the criteria of resistance, good function and durability. It has been demonstrated that unplastered straw bale walls have high resistance in the elastic range, they can absorb energy under dynamic loading or accidentally developed excess energies.

4.1 Characterization of straw for construction [5]

The quality of straw materials and products is influenced by the following characteristics:

The lower the **humidity content**, the more favorable it is, depending on the baling season, storage and transport. Starting with a 20% humidity, at a temperature higher than 5ºC, the straw bale is subjected to decay. These bales should be abandoned even if at the time of construction they are extremely dry, because problems may occur if the wall becomes wet.

Density varies depending on the type of straw, the level of humidity and the degree of compression of the bale. Dry density should be at least 112 kg/m^3, an essential condition if the bale is intended to be used for load bearing walls.

Length of fibers – in order to be adequate for use in construction, straw bales should be made from long fibers; short fibers make the bales unstable.

Origin of fibers – rice straws are better than other cereal straws due to their high silicic acid content, which protects against decay.

4.2 Types of straw bales

Wheat straw bales bound with 3 strings [1] were subjecte to a 579 kPa load, being compressed to half their initial height without residual deformation. The measured values for the elastic modulus and the Poisson coefficient were 538 ÷ 1455 kPa and 0.3, respectively.

Wheat, barley and oat straw bales [4] with a mean humidity content of 9% were subjected to compression with a pressure of 41 ÷ 69 kPa. The resulting elastic modulus was 124 ÷ 179 kPa, and the mean values of the Poisson coefficient were: longitudinal 0.37 and transverse 0.11. Following the tests performed, there was a considerable variation of the elastic modulus between the different types of straw bales; the density of the bale had a greater effect on resistance than the type of cereal, and the Poisson coefficient was higher in longitudinal direction than in transverse direction.

Supercompressed bales [8] were obtained by compression with hydraulic presses to approximately twice their normal density, i.e. 288 kg/m^3, and they were bound again with polypropylene rope.

Subjected to edge strain, unlike wheat straw bales bound with 3 strings that suddenly came apart because of the breaking of the rope, these had a linear behavior up to the limit of 120 kPa and a deflection of 13 mm. The elastic modulus obtained was 6839 kPa, much higher than in the case of ordinary bales.

4.3 Straw bale building systems

Two straw bale building systems (load bearing wall structures and frame structures) are currently used, each system having its own advantages.

The load bearing wall structure (fig. 5) is an ecological construction and a good solution for areas in which building materials are deficient or very expensive.

Figure 5. Straw bale load bearing wall structure, California [1]

The building process involves: construction of the foundation, addition of adequate waterproofing, elevation of bales, mounting of cables and installations in the walls, mounting of door and window frames before the construction of the roof.

The bales are stacked in a casing or are just placed on top of one another. In the latter case, through the addition of mortar (cement) between the bales, thermal bridges are formed.

In bale load bearing wall structures, the compaction of each bale is essential for minimizing subsequent compressions.

Moisture due to water vapors is almost absent since these can cross the wall thickness. In straw bale buildings, no barrier against moisture or vapors is necessary, except for the exposed horizontal surfaces (window sills) and joints between the woodwork and straw bales, which should be carefully designed and insulated.

For protecting the lower part of the straw bale walls against moisture, these should be isolated from the foundation through adequate waterproofing.

A disadvantage of load bearing wall structures is that all these operations last for a relatively long time period. In the event of rain, if the bales become too wet, they must be replaced.

The frame structure (fig. 6) allows for the construction of the load bearing structure and its covering before the straw bales are on site. Thus, the walls can be made of straw bales and weatherproofing is ensured, which significantly reduces the problem of moisture during construction.

If at a given time, a moisture problem in the walls occurs (e.g. the deficient sealing of a window), the bales in cause can be replaced without affecting the primary structure.

Figure 6. Technology for building a frame structure with straw bale non-load bearing walls [5]

In both construction systems, straw bale walls can be plastered using traditional plastering with earth, lime and plaster, decorative plastering, and various combinations of these.

Seismic tests show that the load bearing wall system is more efficient (it has a higher ductility and energy absorption) than the frame system subjected to dynamic loading.

5. Conclusions

The use of agricultural products and waste in the building materials industry is an efficient modality for implementing sustainable development in the construction industry, due to the multiple possibilities for recovering materials and at the same time for reducing energy consumption, which ensures environmental protection.

For waste generators, it guarantees the complete, relatively inexpensive elimination of waste, under environmentally safe conditions, as well as the avoidance of environmental problems and attendant penalties.

The use of agricultural products and waste in the building materials industry contributes to:

- the conservation of natural resources (aggregates, limestone, clay, etc.);
- the reduction of gas emissions that would be generated in the case of the storage or burning of waste;
- the avoidance of overaccumulation of waste in controlled waste dumps;
- the improvement of the environmental image.

The use of agricultural products and waste in the building materials industry opens promising perspectives in the field of ecological construction, deserving more attention and further studies in order to be accepted in the construction industry.

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