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UTILIZATION POSSIBILITIES OF SOME CEREAL PLANT WASTES IN THE CONSTRUCTIONS DOMAIN, IN THE CONTEXT OF AVAILABLE CROPS IN ROMANIA – A REVIEW

BY

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Abstract. In recent years, the use of natural fibers in the composition of concrete became increasingly common. In Romania, an important source of plant fibers suitable for construction industry is represented by cereals, mainly by wheat and corn. The wheat straws are considered with good thermal and acoustic insulation qualities, being durable if are treated in a proper way. The high content of oxygen makes corn cobs to be a good thermal insulator material, being more fire resistant than polystyrene.

The purpose of this paper is to compile some literature data on the use of wheat straw and corn cobs as composite materials in concrete. Its importance comes from the fact that at present, in Romania, the use of such materials is relatively limited and a wider knowledge of these resources could lead to an increase in their use as materials added to concrete.

Keywords: concrete; wheat straw; corn cobs.

1. Introduction

In developing countries, in the housing construction, the materials cost count about 70% of the total costs (Rust, 2014). Moreover, in Europe, the

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energy consumed by the constructions sector represent more than 40% of the total energy consumption and gas emissions, the main responsible for this fact being the cement production and, by default, the concrete production, which are predominantly used in constructions today (Bouasker *et al.*, 2014). In the same time, the urbanization expansion requires a high level of natural resources, and the result is their depletion (Prusty *et al.*, 2016). All these represent very strong reasons to look for alternatives to built cheaper and greener, sustainable and also durable. Researchers have focused on the development of advanced materials to increase the energetic performance and decrease the energy consumption of the buildings (Bouasker *et al.*, 2014). All these characteristics were found in natural fibres, especially in agricultural wastes, because they are annually renewable, cheap, widely available, biodegradable, with no risks for health and safety during handling, and they can be used as reinforcement in concrete (Merta & Tschegg, 2013).

In recent years, the use of natural fibres in the composition of concrete became increasingly common, particularly due to lower costs and reduction in weight of the concrete. Natural fibres used for such purposes are categorized into mineral fibres (*e.g.*, asbestos), plant fibres (including flax, hemp, kenaf, ramie, banana fibres, pineapple leaf fibres, papyrus etc.), and animal fibres (*e.g.*, silk, wool) (Saxena *et al.*, 2011). Plant fibres are classified into three main categories, such as: leaf fibres (*e.g.*, oil palm, banana, sisal, pineapple, abaca leaf etc.), stem fibres (*e.g.*, kenaf, jute, and flax), and seed fibres (*e.g.*, cotton, rice husk, kapok and coir) (Valdés *et al.*, 2014).

An important source of plant fibres suitable for construction industry is represented by cereals, mainly by wheat and corn.

Wheat production is on the first place in total EU-28 grains production, while the grain maize and corn cob mix is on the third place, very close to barley. In Romania, like in many European countries, the wheat and corn crop have an important share in the country`s agriculture. For example, in 2015, Romania ranked the sixth position in the 28 EU Member States regarding the general grain production, the fifth position in production of wheat, and the second place, after France, in corn production. In recent years, the production of these cereals had an upward trend, which involved the same type of trend also for wastes derived therefrom (Eurostat, 2016). This is an additional reason to find technical solutions to reduce their environmental impact.

Throughout the ages, such wastes were used in various domains, including both traditional and innovative ones. For example, wheat straw were used in animal feed, soil fertilizers, pulp and paper, animal bedding, mushroom production (growth substrates), and as nanomaterial for bio-ethanol production or in construction (as roof and insulation material or cobs) (Bäcklund, 2011; Backer *et al.*, 2013; Zhang *et al.*, 2012). Even if their possibilities of use are various, wheat straws are generally by-products neglected, being often burnt in open field (Bäcklund, 2011).

The use of corn cobs is relatively more restricted compared with wheat straws, which includes the animal feed, fertilizer soil from which it was harvested (Ashour *et al*., 2013) and, occasionally, domestic heating (Pinto *et al*., 2012a).

More and more studies focused on the possibility of wheat straw and corn cobs using in constructions, aiming to improve their durability, mechanical strength, but also the resistance on fungus and moisture. However, using plant fibres becoming increasingly attractive instead of composite synthetic fibres (such as fiberglass or carbon fibres), through their wide availability, renewability of raw materials, low costs, sustainability (Saxena *et al*., 2011), and their thermal (Sisman *et al*., 2011) and acoustic (Asdrubali, 2007) insulation properties.

The purpose of this paper is to compile some literature data on the use of wheat straw and corn cobs as composite materials in concrete. Its importance comes from the fact that at present, in Romania, the use of such materials is relatively limited and a wider knowledge of these resources could lead to an increase in their use as materials added to concrete.

2. Wheat Straws Characterization and their Uses

Because they are cheap, renewable, and with good building qualities, straws represent an excellent alternative for traditional wood materials. They are with good thermal and acoustic insulation qualities, being durable if are treated in a proper way to resist moisture and rot. As disadvantages, wheat straws burn easily when they have space between them, can mold if it is not ensured a sufficient ventilation (Bäcklund, 2011), and are with a very large capacity of water absorption (Bouasker *et al*., 2014).

The water absorption coefficient varies between 290 and 400% after immersion in water for 60 min, values considered high compared to those found for flax and hemp. Such values may have both beneficial and deleterious effects, because in the care of their mixture in concrete such fibres mobilize a significant amount of water, leading to the risk of insufficient hydration of the cement and, consequently, to lower resistance of the concrete. On long term, this water absorbed by fibres helps to concrete shrinkage reducing (Bouasker *et al*., 2014).

Before their use as a building material, wheat straws should be treated against mold, due to the high risk to develop mold within straw. Mold can cause damage to the fibre and to the surrounding matrix. Such of treatments consist in the introduction of wheat straws for 24 hours in a saline solution (30 g/l NaCl), and their subsequent rinsing by their keeping for another 24 hours in a 10% NaOH solution (Bouasker *et al*., 2014).

Farooqi & Ali, (2016), studied shrinkage decreasing in normal concrete by natural wheat straw and treated wheat straw introduction, the material obtained being used as pavements. Treated straws mean that they were boiled for two hours, and then they were dried. The concrete recipe contains cement, sand, and aggregates in 1/3.75/1.75 ratio. The sand use in such of high ratio aimed a more efficient straw embedding. This study concluded that wheat straw had a bridging behaviour, because prolong the period from the appearance of a first cracks to the complete damage, so they are proper to be used for reinforce the concrete from pavement applications.

Bäcklund, (2011), performed a study using a sandwich panel with its core based on wheat straw glued with a soy protein based resin, and its sides of the plates woven bamboo fibres. By combining these materials, the author aimed to achieve a 100% natural product, and combining their qualities in the best way, because bamboo presents a very good tensile strength, it is easy to be processed, and has aesthetic properties, and wheat straws provide thermal and acoustic insulations. To improve the mechanical properties, wheat straws were treated with bleach for removing their waxy surface to better react with soy protein. The study results were not as expected, the obtained panel cannot act as load bearing wall to retrieve essential loads, but can act as shear wall which can retrieve a seismic stress up to 9.268 MPa.

Merta *et al*., (2011), realized a research about fracture mechanics of concrete reinforced with hemp, straw, and elephant grass fibres. The authors realized concrete specimens with aggregates smaller 16 mm, water/cement ratio 0.67, and 0.19% by weight of chopped wheat straw of 40 mm length as fibre reinforcement. As reported results, the fracture energy of concrete was improved by 2% using wheat straw fibres, comparing to 70 % using hemp fibres, and 5% using elephant grass fibres. Continuing researches, Merta & Tschegg, 2013 found that the tensile strength of concrete decreased with 7% for wheat straws, 4% for hemp, and 8% for elephant grass fibres. All these results were reported to standard concrete performed without fibres.

Wheat straws may become as such a building material, without any other additions, up to now being built houses from straw bales. Douzane *et al*., (2016), analyzed the hydrothermal performance of a house built by straw bales, in the Picardie region of France. This house has a wooden load bearing frame, which was filled with straw bales. After laboratory and *in situ* tests, the temperature and relative humidity measurements revealed no condensation risk in the walls, except the conditions in which lime plaster coating had high moisture content. Although the environmental comfort is assured, the walls of straw should be monitored in connection with the emergence and spread of mold inside their interior, a claimed condition of toxic mold appearance being a relative humidity above 85%. A dynamic simulation based on experimental results measured in laboratory confirmed that the house made by straw bales ensure a good thermal resistance and a high comfort (Douzane *et al.*, 2016). Chaussinanda *et al.*, (2015), realized a similar study on a straw bales building in Switzerland, with load-bearing walls made by straw bales in thickness of 80 cm and wooden structural frame. There was designed a central wall made by adobe with a role of thermal mass to save more energy with less variation in the thermal comfort. The reported results revealed excellent comfort and indoor air quality in conditions of a proper ratio of openings with triple glassing and a double flow ventilation, the building being considered among the most energy efficient in the administrative structures category. Nowadays, the wheat straw buildings price is roughly similar to those built by traditional materials, but their features are for buildings with standard low energy consumption. With the development of this field, these kind of buildings will become cheaper, and will become a real alternative for buildings performed by wood or brick, given that we are currently facing to the depletion of finite resources (straws are annually renewable) (Chaussinanda *et al.*, 2015).

In conditions in which wheat straws are with significant problems in terms of ensuring their durability in case of their using *per se* in buildings, researches were directed towards the conversion of these straws in ash, which was proved with special pozzolan properties, being suitable for the partial replacement of cement from the concrete composition. The straw ash contains large amounts of SiO_2 (in proportions of 40%), which represent an essential element of pozzolan reaction, with a role in concrete strength increasing (Kaushnood, 2014; Al-Akhras & Abu-Alfoul, 2002). Al-Akhras & Abu-Alfoul, (2002), realized a research on mortar mixes prepared with natural silica, local sand, and crushed limestone fine aggregates, with water/cement ratio of 0.6. They partially replaced sand with wheat straw ash in different proportions: 3.6%, 7.3%, and 10.9%. In case of 10.9% replacement with wheat straw ash, compressive tensile and flexural strength increased in average with 87%, 67%, and 71%, respectively, compared to the control mortar. For all studied variants, the mechanical properties (compressive tensile and flexural) increase in the same time with the increase of ash replacement levels. In case of mortar with 73% wheat straw ash, the authors reported a more packed structure than the control mortar. Along with increasing of wheat straw ash replacement, the necessary quantity of water and initial setting time increased.

3. Corn Cobs Characterization and their Uses

In general, corn plants and corn cereal are used for cattle feeding, and food industry. As wastes, corn cobs are not with a specific application, being used in relative small amounts for house heating or animal feeding (chopped together with maize). Corn cobs may be considered mainly as agricultural wastes which are either disposed by burning on the field (Pinto *et al*., 2012a) or used as fertilizer directly on the harvested field (Ashour *et al.*, 2013).

Corn cobs represent about 15% of the total corn production, being constituted by cellulose, hemicellulose, lignin, protein, and ash in the following percents: 39.1, 42.1, 9.1, 1.7, and 1.2, respectively (Ashour *et al*., 2013). Its density is around 212 kg/m^3, feature which allow its use in lightweight concrete production (Pinto *et al*., 2012a). As a special feature of these agricultural wastes is a very high water absorption capacity of 327%, being necessary 15 days to reach the level of saturation. This long time period is required due to the microstructure and composition of corn cobs, which implies the existence of a capillary network. Although these wastes can absorb such high quantity of water, they keep their integrity, being therefore considered with acceptable water resistance for building applications. As a support of this statement is considered the existence of some buildings in Portugal which have corn cobs in the structure of their external walls. Considering their fire resistance, corn cobs developed a slow combustion process, accompanied by flame and a black gas emission. Comparing to extruded and expanded polystyrene which melted after few seconds of direct flame exposure, corn cobs resisted on fire about 5 min. (Pinto *et al*., 2012a).

The main chemical constituents of corn cobs are oxygen (77.52%), silica (10.06%), aluminium (4.44%), potassium (2.20%), calcium (2.09%), magnesium (1.49%), sodium (1.14%), and iron (1.06%) (Pinto et al., 2012a). The high content of oxygen makes corn cobs to be a good thermal insulator material. Pinto *et al*., (2012a), measured the thermal conductivity of a corn cob particleboard of 5 cm thickness compared to expanded polystyrene, since the two materials have similarities in terms of microstructure and chemical composition. They obtained the value of 0.139 W/m ºC for thermal conductivity and 1.99 W/m^2 ºC for thermal transmission coefficient. The obtained value for thermal conductivity is relatively high compared to the value of expanded polystyrene (0.037 W/m ºC). Paiva *et al*., (2012), obtained a thermal conductivity of 0,101 W/m ºC and a thermal transmission coefficient of 1.89 W/m^2 ºC for the same thickness of tested material. The recorded difference may be justified by the compaction level of the particleboard. Given that these measurements were performed on a panel handcrafted without involving the advanced technology as in the case of polystyrene, it can be concluded that the values obtained can be improved if the process would be similar to that of polystyrene (Paiva *et al*., 2012), and corn cobs can have the perspective of a promising thermal insulating material.

Granulated corn cob was used as aggregate lightweight concrete production, being a sustainable alternative solution compared to currently applied lightweight aggregates as expanded clay, cork, or expanded polystyrene. Pinto *et al*., (2012b), realized a corn cob concrete in a ratio of 6/1/1 (corn cob granulate/Portland cement/water), and an expanded clay concrete in the same ratio (expanded clay/Portland cement/water). The specimens realised with corn cob have a density of 382.2 kg/m^3 , much lower than that with expanded clay (576.3 kg/m^3). The compressive strength maintained the same tendency between the two materials, 120 kN/m^2 and 1,360 kN/m^2, respectively. The very low value obtained by concrete produced with corn cob can be related to the particles size of corn cob, the ratio of components, and curing time. Although the compressive strength is very low, the concrete with corn cob may be used in non-structural applications.

Njeumen Nkayema *et al*., (2016), realized a study on use of corn cob as pore forming agent in lightweight clay bricks, using addition of increasing amount of corn cob (0, 2, 5, 10, and 15% from their weight) in clay slurry, samples obtained being burnt at over 900 ºC. With increasing the corn cob quantity it was observed that apparent and bulk density, flexural strength, and linear shrinkage decreased, and water absorption and porosity increased. Getting a porous material can be of increased interest for partition walls performing, or for thermal or acoustic insulations. Overall decline in physical and mechanical properties may be associated with increased porosity and combustion of corn cob. As a general conclusion of their study is that corn cob can be successfully used as pore forming agent.

Faustino *et al*., (2015), also performed a research on processed granulate of corn cob as aggregate to produce lightweight concrete masonry units. For comparison, they also used expanded clay in making of some samples. The density of obtained products was 1,680 kg/m^3, value which falls within the rules to include the concrete in category of lightweight. In order to reduce water absorption and to improve the adhesion between concrete and aggregates, corn cob granules were coated with cement paste. The samples were tested for water absorption, being held for 14 days in direct contact with water. After completing the test, both types of materials kept their integrity. Also, after their tests on repeated freeze-thaw cycles, they kept an adequate durability. In conclusion, concrete made in these two variants may be used both in interior building applications as well as outside ones. Regarding compressive strength, masonry units realized with expanded clay were two times more strength than those with corn cob.

Because the corn cob granules have a number of drawbacks that hinder the achievement of sustainable construction materials, researchers turned their attention to the use of ash corn cob as a material with pozzolan properties. After analyzing the composition of the corn cob ash, resulted the presence of a significant proportion of SiO_2 (37,...,67.33%) (Binici & Ortlek, 2015; Ikpmonmwosa *et al*., 2015; Oluborode & Olofintuyi, 2015; Okoronkwo *et al*., 2013; Raheem *et al*., 2010; Adesanya & Raheem, 2009), component that is directly involved in the pozzolan reaction and concrete strength improving. The reported specific weight was 1.15 g/cm^3 (Rashad, 2016), 2.18 g/cm^3 (Ikponmwosa *et al*., 2015), or 3.11 g/cm^3 (Binici & Ortlek, 2015). Withal, the corn cob ash was reported with a dry density of 2,180 kg/m^3 and a bulk density of 923 kg/m^3 (Ikponmwosa *et al*., 2015).

Various studies were conducted regarding the use corn cob ash (CCA) as partial replacement of cement in concrete production. Rahheem *et al*., (2010), studied the effect of different classes of additives on the compressive strength of a concrete made with CCA (8% of cement weight). The control concrete realized without any admixture was with a compressive strength of 29.82 N/mm^2 measured at 28 days. By using an accelerator additive, there was obtained a 10% increase of the compressive strength due to the cement hydration accelerator action and to the concrete freezing point decreasing by about 2 ºC. By water reducing and a retarder using, there were obtained an increase in compressive strength by 14.3% comparing to the etalon concrete, and by a plasticizer using, an increase of 29.1%. As a general conclusion of the study, the used additives improved the CCA concrete workability, the greatest effect being attributed to the plasticizer that dispersed the particles of cement and improved the flow properties and resistance to compression in the highest percentage. Ikponmwosa *et al*., (2015), studied the features of „laterized" concrete made with laterite, sharp sand, cement, and CCA (at 0, 10, 20, 30, and 40% replacement levels from cement weight). With increasing the percentage of cement replacement with CCA, the consistency and setting time increased, but workability and concrete density decreased. Central deflection in beams increased in the same time with increasing the percentage of CCA, but remained below of the maximum recommended standard. The density of concrete decreased by about 8% in the case of 40% CCA using, this fact being related to a lower specific weight of CCA than that of Portland cement. The obtained density values for all variants of concrete are in the normal range for concrete with normal weight (2,000,...,2,600 kg/m^3). Compressive strength decreased with increasing of CCA content, this decrease being due to the low content of CaO (6.7%) and of the compound (SiO_2+Fe_2O_3+Al_2O_3) (46.05%). The share of (SiO_2+Fe_2O_3+Al_2O_3) compound classifies the used CCA in Class C Pozzolan, which is a class of weak pozzolan materials. The optimal flexural strength and compressive strength were obtained to 10% CCA content, therefore, this variant of concrete is to be used in low costs housing construction. Oluborode & Olofintuyi, (2015), studied the features of un-compacted concrete with CCA as a substitute for cement in the proportions of 0%, 10%, 20%, 30%, obtaining a maximum compressive strength of 9.04 N/mm^2 within 7 days, 10.89 N/mm^2 within 21 days, and 18.44 N/mm^2 within 28 days, for concrete with 30% CCA content replacement from cement weight. Olafusi Oladipupo & Olutoge Festus, (2012), reported a high strength concrete (35 MPa) with CCA replacement in 0, 10, and 20% from the cement volume. The compressive strength tests led to the conclusion that the 10% CCA variant did not compromise the compressive strength requirements set out for period of 7 days, but did not meet the standards 14, 21, and 28 days. Therefore, CCA is suitable as a partial substitute for cement in the high strength concrete, but needs more time to achieve the designed strength, by a water-cement ratio less than 0.40, and using a super-plasticizer to improve its workability. Adesanya & Raheem, (2009), performed a concrete with CCA as cement substitute by replacing 0%, 2%, 4%, 6%, 8%, 10%, 15%, 20% and 25% by weight, the obtained results showing that CCA may be used as a pozzolan in the situation of which is fulfilled the condition of SiO_2+ Al_2O_3 to represent more than 70%. Even if all concrete variants were with higher setting times than the standard, they may be applicable in cases that require a low level of heat development, as in the case of mass concreting. Adesanya & Raheem, (2010), continued the research using the same proportions of cement replacement with CCA, analyzing the permeability and chemical attack of H_2SO_4 and HCl. Regarding the permeability, the concrete absorption of water dropped at the same time with a more high content of CCA was used. The resistance to chemical attack was improved in the case of concrete variants which contain up to 15% CCA. Binici *et al.*, (2009), showed that the use of CCA in concrete leads to increase the resistance to sodium sulphate as a result of the physical structure more condensed of the CCA than the physical structure of Portland cement.

Binici *et al.*, (2008), studied the durability of concrete containing corn cob and wheat straw ashes (WSA). These mineral admixtures assured a good workability and abrasion resistance compared with conventional concrete, the optimal variant being in case of samples made with 6% CCA. The abrasion resistance was improved with increasing content of CCA and WSA. The same effect was obtained for the resistance to Na_2SO_4. The resistance to abrasion and Na_2SO_4 attack on concrete with CCA was higher than for concrete with WSA. These results recommend the use of CCA and WSA for the production of durable concrete.

4. Conclusions

Wheat straws are with good thermal and acoustic insulation qualities, being durable if are treated in a proper way to resist moisture and rot. Their water absorption coefficient was reported to vary between 290 and 400% after immersion in water for 60 min, which may lead to the risk of insufficient hydration of the cement and, consequently, to lower resistance of the concrete. On long term, this water absorbed by fibres helps to concrete shrinkage reducing.

The fracture energy of concrete was reported to be improved by 2% using wheat straw fibres, but the tensile strength of concrete was reported to decrease with 7%.

The straw ash was reported to contain large amounts of SiO_2, which represent an essential element of pozzolan reaction, with a role in concrete strength increasing. Along with increasing of wheat straw ash replacement, the necessary quantity of water and initial setting time were reported to increase.

Corn cobs were reported with a density about to 212 kg/m^3, feature which allow their use in lightweight concrete production. Although these wastes were reported to absorb a high quantity of water, they keep their integrity, being considered with acceptable water resistance for building applications.

Comparing to extruded and expanded polystyrene which were reported to melt after few seconds of direct flame exposure, corn cobs were reported to resist on fire about 5 minutes.

Corn cobs are considered with perspective for thermal insulation of buildings.

As the wheat straw ash, the corn cob ash was reported with a significant proportion of SiO_2, which allow its use in concrete strength improving.

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POSIBILITĂŢI DE UTILIZARE A UNOR DEŞEURI VEGETALE DE CEREALE ÎN DOMENIUL CONSTRUCŢIILOR, ÎN CONTEXTUL CULTURILOR DISPONIBILE ÎN ROMÂNIA – O REVIZUIRE

(Rezumat)

În ultimii ani, utilizarea fibrelor naturale în compoziţia betonului a devenit tot mai frecventă. În România, o sursă importantă de fibre vegetale adecvate pentru industria construcţiilor este reprezentată de cereale, în principal de grâu şi porumb. Paiele de grâu sunt considerate cu bune calităţi de izolare termică şi acustică, fiind durabile în cazul în care sunt tratate într-un mod adecvat. Conţinutul ridicat de oxigen face ca ştiuleţii de porumb să fie un bun material izolator termic, fiind mult mai rezistent la foc decât polistirenul.

Scopul acestei lucrări este de a compila unele date din literatura de specialitate cu privire la utilizarea paielor de grâu şi a ştiuleţilor de porumb ca materiale de adaos în beton. Importanţa sa provine din faptul că, în prezent, în România, utilizarea unor astfel de materiale este relativ limitată şi o cunoaştere mai largă a acestor resurse ar putea duce la o creştere a utilizării lor ca materiale adăugate în beton.