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NON-AUTOCLAVED AERATED CONCRETE D600 MODIFIED WITH MINERALIZED FIBROUS LICORICE ROOT WASTE

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Abstract. The paper presents a shortened English version of a study on non-autoclaved aerated concrete of density class D600 modified with processed fibrous waste from licorice root. The research is aimed at improving the crack resistance of pore walls, reducing drying shrinkage and involving local plant waste in the production of lightweight wall materials. The fiber was prepared by sorting, grinding, hot-water washing, lime treatment and mild silicate mineralization. Direct addition of untreated licorice root waste delayed setting, destabilized gas expansion and reduced strength. The best composition, NAC-3, contained 3.5 kg/m3 of cleaned and lime-silicate-mineralized fiber. At an average density of 606 kg/m3 it reached a 28-day compressive strength of 3.05 MPa, flexural strength of 0.72 MPa, water absorption of 36% and drying shrinkage of 0.52 mm/m.

Keywords: non-autoclaved aerated concrete, D600, licorice root, plant fiber, mineralization, lime-silicate treatment, compressive strength, flexural strength, shrinkage, water absorption.

Annotatsiya. Qizilmiya ildizidan qayta ishlangan tolali chiqindilar bilan o‘zgartirilgan, zichligi D600 sinfidagi avtoklavlanmagan gazbeton bo‘yicha tadqiqotning qisqartirilgan inglizcha versiyasi keltirilgan. Tadqiqot teshik devorlarining yorilishga chidamliligini oshirish, quritish qisqarishini kamaytirish va mahalliy o‘simlik chiqindilarini engil devor materiallarini ishlab chiqarishga jalb etishga qaratilgan. Elyaf saralash, maydalash, issiq suvda yuvish, ohak bilan ishlov berish va yumshoq silikat minerallashuvi orqali tayyorlangan. Qayta ishlanmagan qizilmiya ildizi chiqindilarini to‘g‘ridan-to‘g‘ri qo‘shish,

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sozlashning kechikishiga, gazning kengayishini beqarorlashtirishga va mustahkamlikni pasayishiga olib keladi. Eng yaxshi kompozitsion NAC-3 tarkibida 3,5 kg/m3 tozalangan va ohak-silikat-mineralizatsiyalangan tola mavjud edi. O‘rtacha zichligi 606 kg/m3 bo‘lgan 28 kunlik bosim kuchi 3,05 MPa, egilish kuchi 0,72 MPa, suvni singdirish 36% va quritish qisqarishi 0,52 mm/m ni tashkil etdi.

Kalit so‘zlar: avtoklavlanmagan gazbeton, D600, qizilmiya ildizi, o‘simlik tolasi, minerallashuv, ohak-silikat bilan ishlov berish, bosim kuchi, egilish kuchi, qisqarish, suvni singdirish.

Аннотация. В статье представлена сокращенная англоязычная версия исследования неавтоклавного газобетона класса плотности D600, модифицированного переработанными волокнистыми отходами из корня. Цель исследования — повысить трещиностойкость стенок пор, уменьшить усадку при высыхании и использовать местные растительные отходы в производстве легких стеновых материалов. Волокно было подготовлено путем сортировки, измельчения, промывки в горячей воде, обработки известью и слабой силикатной минерализацией. Непосредственное добавление необработанных отходов из корня солодки замедляло схватывание, приводило к дестабилизации газовыделения и снижению прочности. Наилучший состав, NAC-3, содержал 3,5 кг/м3 очищенного и обработанного известью и силикатами волокна. При средней плотности 606 кг/м3 прочность на сжатие через 28 дней составила 3,05 МПа, прочность на изгиб — 0,72 МПа, водопоглощение — 36 %, а усадка при высыхании — 0,52 мм/м.

Ключевые слова: неавтоклавный газобетон, D600, корень солодки, растительное волокно, минерализация, силикатно-известковая обработка, прочность на сжатие, прочность на изгиб, усадка, водопоглощение.

1. INTRODUCTION.

When concrete is subjected to shrinkage, a need for deformation will occur. If this deformation is restrained, restraint forces will appear. When a concrete member is cast against an existing concrete member restraint forces may occur due to different needs of movement, which may lead to cracking. Two specific cases are when edge beams on concrete bridges are replaced and when concrete retaining walls are cast against an existing concrete foundation slab. Even though cracks are natural in reinforced concrete during the service state, they can cause durability problems if they become too large. Increased reinforcement amount and addition of fibre reinforcement to the concrete are two possibilities to

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control the cracking. However, guidance of how to design restrained members with regards to crack widths is insufficient in codes used today. Therefore, non-linear finite element analyses were performed in order to increase the understanding of the cracking response in restraint situations and how to design in these situations.

Finite element analyses were compared with test results on tie-rod tests carried out on concrete specimens with ordinary and fibre reinforcement. When using uniform material properties determined from tests, good agreement was achieved for the case with ordinary reinforcement. For the fibre reinforced concrete it was necessary to take into account the heterogeneity of the combined material. A new model, showing good agreement with test results, was proposed to simulate the behaviour of fibre reinforced concrete. When the modelling technique had been verified, it was also used to investigate the cracking response in other applications.

Non-autoclaved aerated concrete is widely used as a wall and heat-insulating structural material because it can be produced without energy-intensive autoclave curing. However, normal-cured aerated concrete is sensitive to the stability of gas formation, early setting and drying conditions. A common problem is the formation of microcracks in thin pore walls, which leads to increased shrinkage and insufficient bending resistance.

Dispersed fibers are usually introduced into cellular concrete to improve crack resistance. Mineral, basalt, polymer and industrial fibers are effective, but they increase the cost of the mixture and do not always correspond to the principle of local resource use. In regions where licorice root is processed, a considerable amount of fibrous plant waste is generated. This waste can be considered as a functional additive, but it cannot be used directly in cement systems because water-soluble sugars, extractives and phenolic compounds inhibit cement hydration and disturb the formation of a stable porous matrix.

The objective of this work was to evaluate the influence of cleaned and lime-silicate-mineralized licorice root fiber on the physical and mechanical properties of non-autoclaved aerated concrete D600. The study compared a reference mix without fiber, a mix with untreated waste, a mix with hot-water-washed fiber and a mix with fully mineralized fiber.

2. MATERIALS AND METHODS.

For the most part, this report makes use of metric units despite the fact that the cement (and concrete) industry, at the time of writing, continues to use nonmetric units for commerce and a mix of units for internal accounting. Nonmetric units are also commonly encountered in the literature on cement. Conversion of units is provided below for the convenience of the reader. It is important to note that some of the conversion factors are given here to more significant figures than can generally be justified in reporting cement data.

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In the increasingly popular industrial ecology paradigm, it is desirable to have industries and industrial processes that are interconnected and interdependent, particularly in the context of having no, or greatly reduced, net wastes by the entire multi-industry complex. In other words, it is desirable to have industries that consume other industries' waste products (the CemStar process, mentioned earlier, is a good example of this). Given that cement and concrete are produced and consumed in huge quantities worldwide, the manufacture of cement to meet this demand insures that enormous quantities of raw materials and fuels will also be required. The manufacture of cement (actually clinker) has virtue in its inefficiencies of high requisite temperatures and long residence times for clinker formation.

The cement industry tends not to distinguish between units of weight and mass but almost invariably conducts its business in the sense of weight. Thus the metric ton, a unit of mass, is treated as if it were a unit of weight; strictly, the conversions to weight are applicable only at mean sea level. Barrel (bbl) as a unit of cement weight (not volume) is no longer used by the cement industry but is frequently encountered in the historical literature. Its weight conversion has varied over the years by type of cement, reporting source, and by reporting region. For original (not re-converted) data reported by the Government, equivalences are as follows:

Portland cement M500 was used as the main binder. Hydrated lime Ca(OH)2 was introduced to provide an alkaline medium, stabilize gas formation and participate in the formation of the cement-silicate matrix. Finely ground quartz sand was used as the siliceous component. Fly ash or finely ground blast-furnace slag, silica fume, gypsum, a polycarboxylate superplasticizer, aluminium powder and water were also included in the compositions.

The fibrous licorice root waste was prepared in several stages: sorting, grinding to a fraction of 3-12 mm, hot-water washing, treatment with a calcium hydroxide suspension, mild silicate mineralization with diluted liquid glass, pressing and drying to working moisture. Hot washing removed soluble extractives, sugars, saponins and phenolic compounds. Lime-silicate mineralization formed a thin mineral layer on the fiber surface, improving its compatibility with the cement-lime matrix.

Table 1

Experimental variants of non-autoclaved aerated concrete D600

Mix	Fiber condition	Fiber dosage, kg/m3	Technological feature

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NAC-0	No fiber	-	Reference aerated concrete
NAC-1	Untreated licorice root waste	3.5	Direct addition of organic waste
NAC-2	Hot-water-washed fiber	3.5	Removal of soluble inhibitors
NAC-3	Cleaned and lime-silicate-mineralized fiber	3.5	Improved fiber-matrix compatibility

The mixture was prepared by dry mixing the mineral components, dispersing the prepared fiber in part of the mixing water with superplasticizer, adding this suspension to the dry mixture and finally introducing aluminium powder. The gas-forming additive was added at the last stage to avoid premature disruption of expansion. Specimens were kept in molds under film for 24 h and then cured under moist and normal laboratory conditions up to 28 days. Average density, settlement of the gas-concrete mass after maximum rise, setting delay, compressive strength at 7 and 28 days, flexural strength, water absorption, drying shrinkage and dry-state thermal conductivity were measured.

3. RESULTS AND DISCUSSION

Chemical control confirmed that the initial plant waste contained a high amount of soluble extractives and reducing sugars. Hot-water washing reduced the content of extractives from 14.6% to 2.6% and reducing sugars from 2.15% to 0.42%. After mineralization, these values decreased further to 1.9% and 0.31%, while the pH of the aqueous extract increased from 5.7 to 9.1. This means that the treated fiber became more suitable for a cement-lime environment.

Table 2

Main physical and mechanical properties of the experimental mixes

Mix	Density, kg/m3	Settlement, mm	Setting delay, min	Compressive strength 28 d, MPa	Flexural strength 28 d, MPa	Water absorption, %	Drying shrinkage, mm/m
NAC-0	604	5	0	2.08	0.44	44	0.78
NAC-1	598	17	110-125	1.18	0.28	53	0.94

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NAC -2	601	8	35-45	2.05	0.49	43	0.68
NAC -3	606	4	0-10	3.05	0.72	36	0.52

The results show that untreated licorice root waste had a negative effect on early structure formation. In NAC-1, the beginning of setting was delayed by 110-125 min compared with the control mix, and settlement after maximum rise increased to 17 mm. The 28-day compressive strength decreased from 2.08 MPa in the control composition to 1.18 MPa. Flexural strength also decreased from 0.44 MPa to 0.28 MPa. These results indicate that untreated organic matter acts as an inhibitor and destabilizes the porous structure.

Hot-water washing partly eliminated the harmful effect of soluble organic compounds. NAC-2 showed a 28-day compressive strength of 2.05 MPa, which was close to the reference mix. Flexural strength increased to 0.49 MPa and drying shrinkage decreased to 0.68 mm/m. Thus, washing is a necessary but not sufficient condition for the efficient use of plant fiber in aerated concrete.

The best performance was achieved for NAC-3 with cleaned and lime-silicate-mineralized fiber. The 28-day compressive strength reached 3.05 MPa, which is 46.6% higher than the control value. Flexural strength increased to 0.72 MPa, or 63.6% above the control value. At the same time, water absorption decreased from 44% to 36%, and drying shrinkage decreased from 0.78 to 0.52 mm/m. The average density remained within the D600 class and amounted to 606 kg/m3.

The improvement can be explained by the combined action of several mechanisms. First, hot washing removes organic inhibitors that delay hydration. Second, calcium hydroxide neutralizes acidic groups on the plant surface and saturates it with calcium ions. Third, silicate mineralization forms a thin calcium-silicate shell, which improves adhesion between the fiber and the cement-lime matrix. Finally, dispersed mineralized fibers reinforce pore walls and limit shrinkage microcracking without disturbing gas formation, because the fiber dosage is relatively low.

Table 3

Comparison of the proposed composition with the closest prototype

Indicator	**Prototype RU2616303C1 D600**	**Proposed NAC-3**	**Change**
7-day compressive strength, MPa	1.40	1.78	+0.38 MPa / +27.1%

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28-day compressive strength, MPa	1.60	3.05	+1.45 MPa / +90.6%
Average density, kg/m3	about 600	606	Comparable D600 density
Reinforcing component	Basalt fibrous waste	Mineralized licorice root fiber	Different nature and preparation of fiber

Compared with the nearest prototype in the same density class, the proposed composition is aimed at a substantial increase in 28-day compressive strength. This result is achieved not by the simple replacement of mineral fibers with plant raw material, but by controlled preparation of the licorice root fiber, including fractionation, hot washing, chemical control, lime neutralization and mild silicate mineralization. From a practical point of view, the composition may be used for wall blocks, partition slabs and heat-insulating structural elements of density class D600. It also allows local licorice root processing waste to be utilized in building materials.

When the concrete shrinks, there is a need for deformation. About this deformation prevention of the emergence of forced forces. When pouring concrete element against the existing element concrete construction, forcing forces can occur due to different movement needs, which can cause cracking. Two typical examples are edge beams on concrete bridges if the replacement and retaining walls are thrown against the existing foundation plate. Although it is natural during the service life, cracks may appear in the reinforced concrete structure if they are too large, cause durability problems. Increasing the amount of reinforcement or using fiber reinforcement in concrete are different ways to limit and control cracking. Guidance on how to measure the structures to be affected The current rules are insufficient in terms of the width of the cracks. Therefore non-linear finite elemental analysis was performed for for to increase to understand for the process of cracking in forced situations, as well as what volume to be such situations.

4. CONCLUSIONS.

1. A composition of non-autoclaved aerated concrete D600 with 3.5 kg/m3 of cleaned and lime-silicate-mineralized fibrous licorice root waste was developed.

2. Untreated licorice root waste worsened the properties of aerated concrete: 28-day compressive strength decreased to 1.18 MPa, water absorption increased to 53%, and drying shrinkage increased to 0.94 mm/m.

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3. Hot-water washing reduced soluble organic inhibitors and partly restored strength, but the maximum effect was achieved only after lime-silicate mineralization.

4. The rational composition NAC-3 had an average density of 606 kg/m3, compressive strength of 3.05 MPa, flexural strength of 0.72 MPa, water absorption of 36% and drying shrinkage of 0.52 mm/m.

5. The improvement is related to better adhesion between mineralized plant fiber and the cement-lime matrix, as well as dispersed reinforcement of pore walls.

6. The proposed approach expands the raw-material base for non-autoclaved aerated concrete and supports the resource-saving use of licorice root processing waste.

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