PRACTICAL APPROACH FOR PRODUCTION OF BACTERIA-BASED AGENT-CONTAINED LIGHT WEIGHT AGGREGATES TO MAKE CONCRETE SELF-HEALING

R.M. Mors[1] and H.M. Jonkers[1]

[1] *Faculty of Civil Engineering and Geosciences, Materials & Environment section, Delft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands - e-mail: R.M.Mors@tudelft.nl and H.M.Jonkers@tudelft.nl*

Keywords: self-healing, concrete, bacteria, agent, LWA

ABSTRACT

A functional experimental concrete system has been developed in our lab, in which a two component bacteria-based healing agent contained in a protective reservoir is included in the concrete mixture. Incorporated bacteria have the potential to produce copious amounts of calcium carbonate based crystals from supplied mineral precursor compounds. Precipitates of the carbonate mineral seal and block occurring cracks. Particles of expanded clay, a type of light weight aggregate (LWA), were chosen as protective reservoir in which the bacteria and precursor compound are contained. Most effective method for intrusion of healing agent in LWA is by vacuum impregnation, a rather expensive process. In this work a more economically feasible in-situ approach is proposed, still gaining the required healing capacity. Prior to mixing LWA are pre-wetted with a warm liquid impregnation solution (80°C) carrying bacterial spores and mineral precursor compounds. This alternative production process is economical and practically more straightforward and functionally additionally beneficial as water-saturated LWA contribute to internal curing. Benefit of the novel approach is the reduced cost of healing agent production and improved practicality directly at a concrete plant, as commonly available equipment can be used. First tests indicate sufficient healing capacity remains after the wet mixing stage and internal drying by cement hydration.

1. INTRODUCTION

Lightweight aggregates (LWA) are used in lightweight concrete structures. Commonly expanded clay aggregates are used. These are also chosen in this research project as LWA to charge with a two component healing agent, consisting of bacteria and nutrients. This 'healing agent' should give the mixture the ability to autonomously block cracks by calcium carbonate production activated by ingress water [1]. In lightweight concrete applications a large fraction of aggregates consists of LWA, therefore a relatively low amount of nutrients need to be included into the LWA to give concrete sufficient healing capacity. Minding ability for in-situ charging of the LWA with commonly available equipment, a method is proposed based on techniques routinely applied in lightweight concrete industry for pre-wetting. In practice often LWA are soaked in water or sprayed for prolonged periods of time until saturation [2]. Saturated particles are necessary when high working pressures are expected, for instance when pumping, to avoid reduction of available water for cement hydration. In other practical cases partial saturation may be sufficient, for instance by supplying absorption water for LWA during the mixing process. Raising

the water temperature can potentially result in more liquid intrusion in LWA [3], helping to evacuate entrapped air in the particles. Another benefit of heating the water for healing agent preparation is that solubility of required bacterial nutrients is higher at elevated temperature, so that concentrations in the intruding liquid are increased. In this case LWA can be soaked in a heated water bath or sprayed with hot nutrient containing liquid before addition to the concrete mixture.
In the EuroLightCon project [4] expanded clay particles have been shown to have different water absorption in wetting state and drying state. The significant hysteresis may have to do with the denser outer shell of the expanded clay particles, creating slow moisture exchange between the inside of LWA and the environment. This inkbottle effect may be beneficial, as the nutrient carrying liquid may remain inside the particles for prolonged period of time, avoiding premature loss to the surrounding cement paste during the mixing stage.

2. MATERIALS AND METHODS

For absorption, expanded clay particles were immersed in warm water saturated with nutrients and suspended bacterial spores. While LWA soak, saturated solution draws into the pores, where nutrients will deposit due to lowered ambient temperature.
In two initial tests 5g LWA (room temperature) were submerged for 15 or 30 minutes in 10mL saturated solution (350g/L calcium lactate) at elevated temperature (80°C), subsequently drained, rinsed 1 minute in a tap water bath (250mL) to remove superficial nutrients and dried in an oven (110°C) or at room temperature. From increase in mass the amount of nutrients deposited inside LWA could be estimated.
For larger scale tests an induction heated mixer was used (Kenwood KM070 series, Cooking Chef Major). Tap water (1.5L) was heated to 80°C under continuous stirring (22rpm) before nutrients were added (350g/L calcium lactate), bacterial spores were dispersed 2 minutes before LWA (1-4mm) were added (2kg). LWA were immersed for 30 minutes, drained and applied wet in the mortar mixture. A 5 gram sample was rinsed in 250mL of tap water for 2 minutes and dried at room temperature for determination of amount of healing agent accumulated inside the LWA.
Mortar prisms were made in triplicate according to the procedure by Wiktor and Jonkers [1], using plain LWA, soaked LWA and two types of vacuum treated LWA. Both types of vacuum treatments were with nutrients according to previous tests [1], but in one case the LWA have been subsequently vacuum impregnated with water and oven dried (110°C) before use. In all cases LWA were wetted before use in the mortar mixture. Furthermore, to test potential effect of LWA-leached calcium lactate on compressive strength, mortar cubes were prepared with varying amounts of calcium lactate. Calcium lactate was dissolved in the mixing water at different ratios by weight of cement (0%, 0.5%, 1%, 4%). Compressive strength tests were executed following European standards (NEN-EN 196-1).

3. RESULTS AND DISCUSSION

After drying, samples of expanded clay showed a mass increase of 6% by weight of LWA for 1 minute rinsing, either dried in the oven or in lab air, and 3.5% wt. for 2 minute rinsing. Content of nutrients is expected to be 3.5-6% by weight of LWA when it is applied to the concrete mixture, which is approximately equal to 3-5%wt. cement.

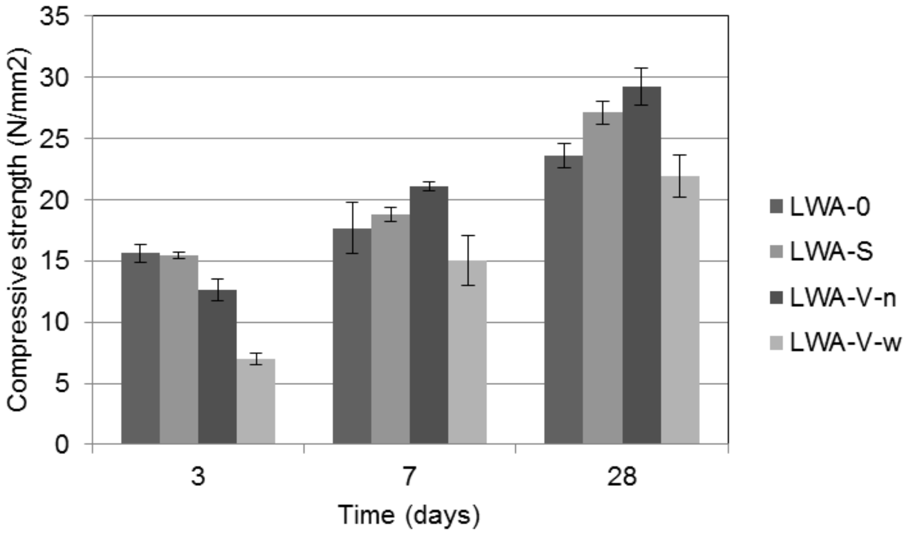

Figure 1: Compressive strength mortars with LWA;
0 = control, S = soaked, V-n = vacuum only nutrients, V-w = vacuum also with water.

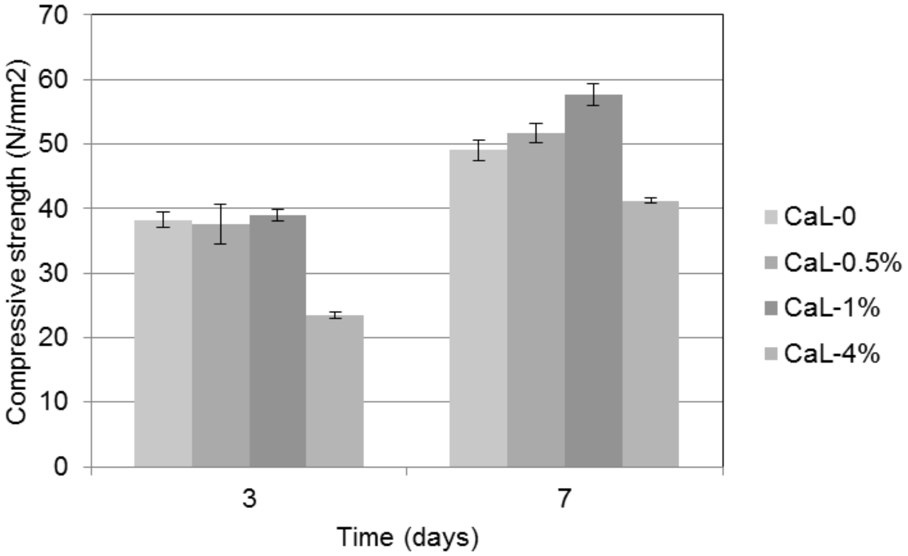

Figure 2: Compressive strength mortars with calcium lactate (%wt. cement).

In case of the oven dried LWA sample, the surface was found notably white of colour, indicating deposition of calcium lactate on LWA surface. This effect was expected, since the solubility is higher at elevated temperature. Calcium lactate was apparently transported with the water, out of the pores during the drying stage, leaving calcium lactate at the surface upon evaporation of the water. In case of drying at room temperature the content of nutrients was the same as the oven dried sample, while the LWA still showed dark colour. Here it is expected that the calcium lactate remained mostly inside the pores, rather than being deposited on the surface. Nutrients at the surface can easily disperse in mixing water. Superficial nutrients are also expected for LWA that have been vacuum impregnated and dried at elevated temperature (LWA-V-w) before use in the concrete mixture. Compressive strength results for specimens made with these LWA show quite different strength development, indicating substantial nutrient loss (Figure 1), since similar decrease in strength is also seen for addition of nutrients at 4%wt. cement (Figure 2).

Internal curing is a process in which water is drawn out of the saturated LWA when cement hydration proceeds [5]. Release of water plus nutrients is also expected for LWA containing healing agent constituents, being embedded in setting concrete. For internal drying, again temperature difference is expected beneficial. Assuming isothermal conditions for lightweight concrete hardening, temperatures are equal to surrounding atmosphere. When applying LWA wet, solubility at a given temperature is expected to be the maximum to be released when the water is drawn from LWA by capillary action. Given a temperature of the saturated solution of 80°C (350g/L) and an atmosphere of 20°C (80g/L), a theoretical nutrient loss of 80/350 is expected during hydration, which is 1/4-1/5 of the total charge. Indication for this shows by comparing compressive strength results in figure 1 and 2. Compressive strength results indeed show relation to an expected loss of nutrients between 0.5 and 1%wt. cement. Still, significance of nutrient loss should be confirmed in future experiments.
Although some loss of nutrients from impregnated LWA occurred during the concrete mixing, sufficient amounts seem to remain to serve as healing agent. In practical cases it can be thought of using a heated water bath, instead of a mixer. An alternative pre-wetting process may be to spray appropriate amounts of heated saturated solution onto the LWA in the concrete mixer, before adding the remaining concrete constituents. Since pre-wetting time is limited, the methods proposed may not be appropriate for pumping purposes. For latter application, alternatives may still be vacuum treatment or thermal treatment at the LWA plant.

4. CONCLUSIONS

Practical methods for healing agent preparation for application at the full scale are being considered. The objective is to increase the healing agent production while making use of commonly available equipment. One option is to impregnate larger quantities of LWA with healing agent constituents on-site. Proposed is a method in which dry LWA are immersed in a saturated solution of constituents at elevated temperature, before addition to the concrete mixture. First results indicate that sufficient nutrients remain in the LWA for healing purposes after wet mixing and subsequent concrete setting.

ACKNOWLEDGEMENTS

Financial support from Agentschap NL (grant IOP-SHM01018) for this work is gratefully acknowledged.

REFERENCES

[1] V. Wiktor, H.M. Jonkers, Quantification of crack-healing in novel bacteria-based self-healing concrete, Cement and Concrete Composites 33(7) (2011) 763-770.
[2] ACI 213R-03, Reported by ACI Committee 213, Guide for Structural Lightweight-Aggregate Concrete, ACI, 2003.
[3] O.M. Jensen, P. Lura, Techniques and materials for internal water curing of concrete, Materials and Structures 39(9) (2006) 817-825.
[4] CUR H82R20, The effect of the moisture history on the water absorption of lightweight aggregates, ISBN 90 376 0168 5, 2000, 21p.
[5] P. Lura, Autogenous deformation and internal curing of concrete, Ph.D. thesis, Delft University of Technology, Delft, The Netherlands, 2003.