Use of Recovered Toner Powder to Enhance Durability, Engineering and Sustainability Performance of Structural Elements

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Introduction

Background: The durability of concrete is a key indicator of the long-term performance of reinforced concrete structures. Enhancing durability can reduce maintenance requirement and will have positive effects on whole-life costs, material demands and usage and thus the environmental impact of the structure itself.

One of the primary drivers of damage to, and deterioration of, reinforced concrete is the ingress of moisture through cracks and pores inherent in the material. It has been found that materials composed of hydrophobic particles, when used as admixture within concrete, can improve the concrete's ability to impede water ingress and one such material is Recovered Toner Powder (RTP).

In recent studies, carried out at the University of Dundee, further to its initial application as a pigment for concrete, RTP was found to increase the water resistance of a concrete mix. As a waste material, RTP can be reclaimed and utilised to help the aims of the construction industry in terms of enhanced service life and sustainability of reinforced concrete structures and consequently national infrastructure.

Range of concrete colours possible using recovered toner ink (Newlands, et al, 2018)

Project aims: The project aimed to investigate the effects of RTP on the main modifiers of durability in concrete, when used as an admixture, including:

- Resistance to Water Absorption
- Resistance to Carbonation
- Susceptibility to water penetration
- Chloride diffusion
- Electrical resistivity
- Compressive Strength
- The Fresh Properties of the Concrete

This allowed comparison of RTP mixes to the properties of conventional mixes and mixes containing commercially available waterproofing additives.

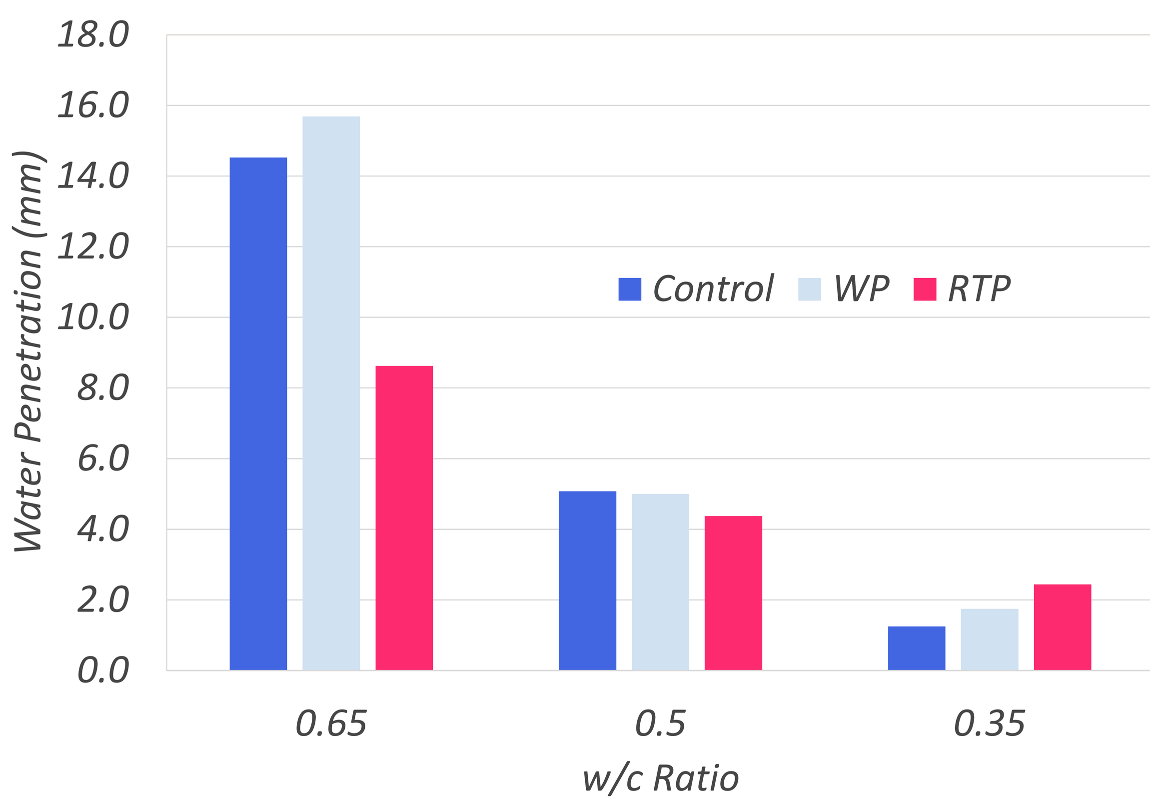
The project also sought to determine the potential use of RTP to reduce the required cement content in a mix to achieve a comparable durability performance in the key areas, alongside investigating the potential of RTP to reduce the reliance on increased cementitious material and increased cover specifications to improve the durability of a mix in design.

The effects that RTP has on these factors was used to determine impact on cost and sustainability of concrete.

Implications for Design

Improvements in the Key areas of Durability:

It was found that RTP concrete has the potential to be adopted to allow specification of concrete with high levels of durability performance in the areas of water penetration, chloride diffusion, carbonation depth, electrical resistivity and sorptivity with. It may allow designers the ability to specify a lower strength concrete that exhibits the durability performance of concretes with lower w/c ratios and higher strength. If the outcomes from the research can be replicated and reproduced consistently in the field, there may be scope for consideration of codifying the use and specification of RTP admixtures within the design standards.



Influence of RTP and commercial water proofer (WP) on water penetration of concretes.

Improvements in Sustainability and Cost:
Calculations showed that the cradle-to-gate embodied CO_2 in the mixes only differed by around 2 to 4 % between the RTP, WP and Control samples. To allow for similar strengths, however, the control mix offers a 4% reduction in costs over the RTP mix and an 11% decrease in embodied carbon due to this increase in CEM I required to overcome the reductions in strength caused by adding RTP to a concrete. Although CEM I offered better economic and environmental benefits when specifying for strength, durability is a key indicator of performance and is often still a desirable feature of a concrete and a comparable strength will not always equal similar durability performance.

Mix Type	w/c Ratio	Strength (MPa)	Cost, £/m³	eCO_2, kg/m³
Control	0.48	51	95	164
WP	0.46	46	123	175
RTP	0.55	37	85	142

Cost, eCO_2 and strength required to achieve desired performance in water penetration of 6mm

Mix Type	w/c Ratio	Strength (MPa)	Cost, £/m³	eCO_2, kg/m³
Control	0.42	57	103	189
WP	0.47	45	120	164
RTP	0.54	37	86	144

Cost, eCO_2 and strength required to achieve desired performance at a depth of carbonation of 7mm

At desired performance levels for water penetration and carbonation, the RTP mix offered lower cost and embodied CO_2 over the other mixes. The RTP mix reduced the price of the concrete by around 10% and the cradle to gate embodied CO_2 by 13% over the control concrete in order to achieve the desired water penetration resistance. This was also seen in when carbonation was the chosen durability indicator.

Conclusions

It was discovered that RTP as a waterproofing admixture can impact upon the compressive strength of a concrete but can notably improve the durability of a mix in the key areas.

A balance then must be struck between the strength of a concrete and its short and long-term durability performance when specifying RTP admixtures. RTP can be said to have potential for designers when performance and durability are of primary concern.

Carbon dioxide emissions from concrete and its embodied carbon dioxide are directly proportional to the cement content (CEM I) in a mix. With the RTP admixture reducing the need for increased cementitious materials whilst maintaining and often improving the performance of the concrete, this admixture offers clear savings on both the monetary costs and eCO_2 of a concrete.

RTP has potential to be adopted to improve durability performance in the areas of water penetration, chloride diffusion, carbonation depth, electrical resistivity and sorptivity with. It may allow designers the ability to specify a lower strength concrete (eg in precast concrete elements where strength may not be the driving factor) that exhibits equivalent durability performance of concretes with higher strength.

Adoption of design and specification in line with the use of such recovered/recycled materials can only help contribute to the reduction of the substantial environmental impact of concrete production and utilisation.

Future Work

This project focused mainly on using RTP in conventional in-situ, CEM I type concrete mixes. Further work could be carried out in these areas:

- Concrete mixes which contain sustainable cementitious materials such as GGBS and fly ash could be used. These materials often improve the strength of concrete and thus the durability and are already in use within the industry.
- Further investigation should be undertaken on the potential whole-life cost savings that any reductions in the need for maintenance that a more durable RTP concrete mix would offer.
- Work could be carried out on precast concrete samples to analyse the benefits of using RTP in this way. In precast, non-structural members where the long-term durability is of primary importance to the manufacturer and designer, the strength of the concrete may be of secondary concern and so any reduction in such by the RTP admixture may not be as significant.

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