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RESEARCH ARTICLE

Proof of concept: Green Grass in Novel Waste Plastics Concrete to Mitigate the Effects of Climate Change

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ABSTRACT: The growth in population and development in industry has led to enhanced construction technologies. As a result, the need for more buildings arises which is followed by more energy consumption and more waste. Concrete is one of the most used materials in construction. However, the production of Portland cement consumes a lot of energy and produces a large amount of carbon dioxide which is emitted into the atmosphere. This in turn impacts on the ozone layer and contributes enormously to climate change. Moreover, there are huge amounts of waste, especially plastic waste, which are produced and delivered to landfill which also impacts significantly on the environment. The utilisation of waste plastic in concrete would help to mitigate the problem of waste by developing a wide range of environmental-friendly special concretes which will ensure both environmental protection and the achievement of appropriate technology. This paper looks at an innovative way of utilising waste plastics for the manufacture of unique concrete types for use in the built environment. The paper is proof of concept, being mainly to show-case one example of the many possibilities of formulating concrete for a wide range of low to medium strength applications. The paper pursues a unique example of composite concrete made from both waste plastics and bio-waste. The preliminary research combines waste plastics and wood waste – saw dust. The aim was to produce a special concrete with special character such as concrete with grass growth, for aesthetical concrete and/or for applications in sports fields or playgrounds. The concrete was made with 100% waste plastics aggregates, with saw-dust waste incorporated to support the growth of grass.

Keywords: Plastics, waste, climate, concrete, environment.

1. INTRODUCTION

The challenges posed by climate change are increasingly becoming more concerning, and serious action needs to take place immediately. Most world leaders agree with this argument, but meaningful change has been elusive. The United Nations Framework Convention on Climate Change (UNFCCC) is the main avenue for global realisation of any efforts towards mitigating the effects of climate change. UNFCCC was formed in 1994, and is the culmination of many years of intricate talking and negotiations, culminating in the Kyoto conference and agreement in 1997. The protocols committed parties by setting internationally binding emission reduction targets. It is through UNFCCC that both developed and developing countries are facilitated to work together to meet agreed emission targets. After eight years of attempting to reduce the targets depending on individual country efforts, the UNFCCC came to force in 2005, taking the previously loose agreements a notch higher. Here key mechanisms were put in place to facilitate global engagement and cooperation. The Clean Development Mechanism (CDM) projects were muted, which were to use Certified Emission Reduction (CER) units as the trading currency to quantify emission reductions. In the currency, one CER unit is the equivalent of the reduction of carbon dioxide emission into the atmosphere by one

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tonne. The entire Emission Trading Scheme (ETS) was to ensure continuity of the mitigation of the effects of climate change. In addition, at Kyoto, an agreement was reached, to assist developing countries to adapt or mitigate against the adverse effects of climate change, and a special fund – Adaptation Fund (AF) was set up for this purpose, to be managed by an AF board (AFB).

The deterioration of the effects of climate change has shown that the agreements set under the UNFCCC are clearly not sufficient as the deterioration of the effects is worrying. The effects require a multi-disciplinary and multi-pronged approach in order to make meaningful change. For materials researchers, there is no limit to the potential contribution that development of sustainable building and construction materials can make. It is well known that the building and construction sectors have an enormous contribution to the global carbon dioxide emission into the atmosphere. With this large contribution to global emission, the manufacture of concrete forms a disproportionately large chunk. For this reason, research into sustainable concrete is a well-known avenue for mitigating the effects of climate change. Whereas the most significant and impactful approach is that towards the replacement of cement, it is also well recognised that replacement of natural aggregates also has notable achievements. For this reason, there have been efforts devoted to utilisation aggregates from construction and demolition waste (CDW), as well as from artificial aggregates. Artificial aggregates are varied and can be based on a wide range of natural, industrial or bio-materials for example from agricultural waste. Thus, the utilisation of natural, industrial, and agricultural waste and by-product materials is increasingly being considered in a wide variety of socio-economic spheres in both technological and environmental contexts.

Plastic waste is increasingly becoming an environmental menace on land and in the sea. Its application in concrete would help to mitigate the problem of waste by developing a wide range of environmental-friendly special concretes which will ensure environmental protection, achievement of appropriate engineering properties [1-3]. Certain niche concrete applications require porosity and/or perviousness, where the aggregates play a far bigger role compared to the role played by cement and/or sand [4-6]. Other applications require lightweight construction [7,8]. The character of waste plastics means that plastics are very well placed as materials for the imparting the lightweight and/or porosity in concrete, for special characteristics for niche applications.

Polypropylene (PP and Polyethylene Terephthalate (PET) are some of the most commonly encountered streams of waste plastics [9,10]. This paper looks at an innovative way of utilising PP waste plastics for the manufacture of unique concrete types for use in the built environment [11]. The paper is proof of concept, to show-case the possibility of formulating concrete for a wide range of low to medium strength concrete applications. The paper pursues a unique application, by investigating the potential for composite concrete made from both waste plastics and bio-waste. It combines waste plastics and wood waste – saw dust, with the aim of producing a special concrete that not only performs in the environmental, structural as well as in the aesthetical sense.

2. MATERIALS

Portland cement: Commercial Portland cement (CEM I – 42.5 N) was used as the control binder. It was supplied by Jewson UK Ltd. of Caerphilly, South Wales, UK. It was manufactured as per BS EN 197 - 1:2011 [12]. The physical and chemical properties are shown in Tables 1 and 2 respectively.

Table 1: Physical properties of Portland Cement

	Properties	PC
1	Insoluble Residue	0.5
2	Bulk Density (kg/m^3)	1400
3	Relative density	3.1
4	Blaine fineness (m^2 /kg)	365
5	Colour	Gray
6	Glass Content	-

Aggregates: Polypropylene (PP) plastic is a thermoplastic polymer and is used on a wide variety of applications including in construction, packaging and in textiles. PP comes in many forms and colours as shown in Figure 1a. Figure 1b shows the shredded propylene aggregates used in the current work. It consisted of flexible leathery aggregates of 5-20mm in diameter. The aggregates were excessively flaky and needed significant vibration time to align in a horizontal formation.

The PP plastic waste was provided by a private construction company - Speedbuild UK Ltd.

Table 2: Chemical composition of Portland cement.

No.	Oxide	PC
1	Lime (CaO)	63
2	Silicon Dioxide (SiO_2)	20
3	Aluminium Oxide (Al_2O_3)	6
4	Magnesium Oxide (MgO)	4.21
5	Iron Oxide (Fe_2O_3)	3
6	Manganese Oxide (MnO)	0.03-1.11
7	Sulphide (S_2)	-
8	Sulphur Trioxide (SO_3)	2.3
9	Alkalis (Na_2O, K_2O)	-
10	Loss on ignition	0.8

3. METHODOLOGY

Two waste plastic concrete test regimes were adopted. The first regime comprised of waste plastic aggregates, Portland cement and water. The second regime had all these three ingredients, but also contained wood sawdust to encourage growth of grass.

3.1 Regime without Grass

The regime without grass comprised of two phases. During Phase 1 (see Table 3), the total amount of cement and waste plastics used were kept constant. Mixes 1 and 2 were made, comprising of waste plastics (WP), cement (C) and water (W). The absence of sand was to make mixes with an open porous texture for the proposed growth of grass. The waste plastics were bound using 10% PC by weight of the waste plastics. The two mixes were at two w/c ratios, 0.3 and 0.5. Both mixes visually appeared wet and of good workability.

(a) (b)

Figure 1: (a) Typical propylene plastics showing variety of colours; (b) Shredded polypropylene plastic flaky aggregates (WP) used in the current experiments.

Table 3: Mix composition without grass *(kg/m³)* *

ID	Mix Code	C	WP	T	W	Visual appearance
			Phase 1			
1	C10W0.3	420	360	-	140	Wet
2	C10W0.5	420	360	-	210	Wet
			Phase 2			
3	C20W0.3	1008	432	-	336	Wet
4	C20W0.5	1008	432	-	504	Wet

Notes: * C-Portland cement; WP – Polypropylene plastic waste; T-Sawdust; W – Water

During Phase 2, Mix formulations Mix 3 and 4 were cast. They aimed at denser formulations, and incorporated higher waste plastics and bound with 20% PC. The two mixes were once again made at two w/c ratios, 0.3 and 0.5. Both mixes continued to visually appear wet and of good workability. This suggested that the use of clean waste plastics can result in workable concrete. Some unpublished work has shown that impurities in waste plastics can sometimes result in higher water demand.

For mixing, all the dry ingredients - cement and waste plastics were placed in a concrete mixer and thoroughly mixed before adding the required amount of water. For mixes containing saw dust, the saw dust was also added during the mixing of dry ingredients, before the addition of water. The wet mixture was placed in 100 mm×100mm×100 mm cube steel moulds and compacted in three layers using a square steel rod. Efforts to vibrate the concrete in the normal manner was not successful as the waste plastics were rather too light and the mixed material heaved significantly. For this reason, hand compaction was adopted, and weights placed on top of the fresh concrete in the steel moulds to prevent heaving, until the cement had set. Demoulding was carried as for normal concrete, after 24 hrs. The waste plastic concrete cubes placed in a water bath to cure at room temperature (20±3°C), for 7 and 28 days.

Testing for density: These tests were carried out in accordance with BS EN 12390-7:2019 [13], after curing for 7 and 28 days in water. An average of results from three test specimens was used for data points. Due to the preliminary nature of the research programme, the density tests were carried out only on the mixes made without grass. This was to study the effect of using waste plastic (not grass or saw dust) on the density of concrete. The growth of grass was meant to be proof of concept only, and hence no tests were carried out on concrete with grass. This aspect is for future more detailed investigation.

Testing for compressive strength: These tests were carried out in accordance with BS EN 12390-2:2019 [14], after curing 7 and 28. An average of results from three test specimens was used for data points. Again due to the preliminary nature of the research programme, the compressive strength tests were carried out only on the mixes made without grass, mainly to study the effect of using waste plastic (not grass or saw dust) on the compressive strength of concrete.

3.2 Regime with Grass

For the waste plastics concrete mixes that were meant to promote the growth of grass, various strategies were instrumented. To promote growth of grass, all regimes with grass seeds were made at a w/c ratio of 0.5, and varying amounts of saw dust (See Table 4). The mixes with grass were a development of mixes 2 and 4 in Table 3, which had a w/c ratio of 0.5 but at two levels of PC content (10% and 20% respectively). The amount of saw dust was varied in each mix series. In one particular mix (Mix 4a) and excessively high amount of waste plastics was used, to assess the effect of density on grass growth.

Table 4: Mix composition with grass *(kg/m³)*
Notes: * C-Portland cement; WP – Polypropylene plastic waste; T-Sawdust; W – Water

ID	Mix Code	C	WP	T	W	Visual appearance
2a	C10T10W0.5	378	324	18	190	Wet
2b	C10T20W0.5	378	324	36	190	Wet
2c	C10T30W0.5	378	324	54	190	Wet
2d	C10T40W0.5	378	324	72	190	Dry
4a	C20T10W0.5	756	324	18	378	Dense
4b	C20T20W0.5	630	324	36	315	Wet
4c	C20T30W0.5	630	324	54	315	Wet
4d	C20T40W0.5	630	324	72	315	Wet

For grass growing, cubes that had cured for 28 days were used, after removal from the curing tanks. Grass seeds were mixed with a small quantity of topsoil and a layer of approximately 5-10mm of the soil-grass seed mixture spread on top of the waste plastic concrete cube surfaces. The cubes were then placed in plastic containers, which were kept at room temperature (20±3°C) and water added using a sprinkler on a regular basis. Germination and growth of grass was monitored on a regular basis, carefully assessing the strength of the germination, rate and condition of growth.

4. RESULTS AND ANALYSIS

4.1 Test specimens

Figure 2 shows a typical 100 mm×100mm× 100 mm cube made using the flaky aggregates from polypropylene waste plastics. The cube edges were very rugged, due to loosely adhered plastic aggregates, especially at the top finished surface. It was possible to coat the entire concrete cube with a cement paste, presenting a better finished product. The cubes were lightweight and some floated in water as shown in Figure 3.

4.2 Density

Figure 4 illustrates the densities of selected mixes (mixes without grass), showing the effect of increasing the w/c ratio and the content of cement on the density of concrete mixes containing waste plastics. The results show low densities in the range of 800 – 1200 kg/m³, suggesting that the concrete for some of the mix formulations could float in water as mentioned earlier. There were also some medium range densities of 1400 kg/m³, although this still suggested very lightweight concrete, considering that typical normal concrete has a density of circa 2400kg/m^3. This lightweight nature is consistent with concrete containing plastics [1-11].

Figure 2: Concrete cube made using 100% replacement of natural aggregates with polypropylene (PP) plastic waste (WP-Concrete).

Figure 3: An exhibition of the wide variety of concrete containing waste plastics, showcasing growing of grass and floating of the concrete in water (concrete in the plastic container), among other unique characteristics.

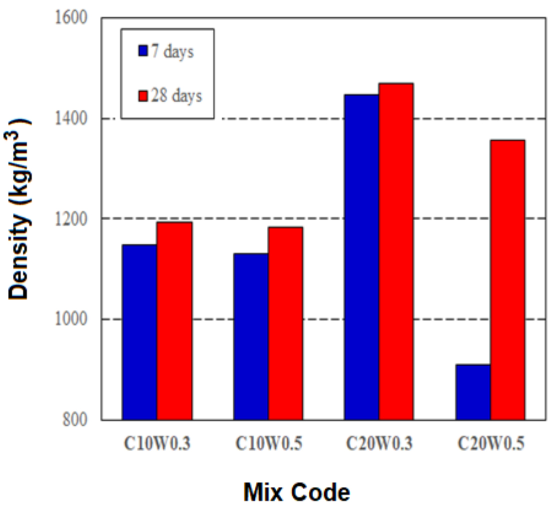

Figure 4: Effect of increasing the w/c ratio and the content of cement on the density of selected concrete mixes containing waste plastics.

4.3 *Compressive Strength*

Figure 5 illustrates the compressive strength for selected concrete mixes containing PP waste. The figure shows the effect of increasing the w/c ratio and the content of cement on the compressive strength. It shows that when the appropriate amount of cement is used at low-medium w/c ratios, it is possible to achieve usable strength values.

For masonry, the standards for concrete and clay masonry BS EN 771-3 [15] and BS EN 771-1 [16] respectively do not specify any strength values, and the manufacturer is left to declare the performance. Thus, achieving 10N/mm^2 (for mix C20W0.3) suggests clear potential. Upon further research, the repeatability of outcomes and precise code of practice can be developed on how to utilise waste plastics in construction.

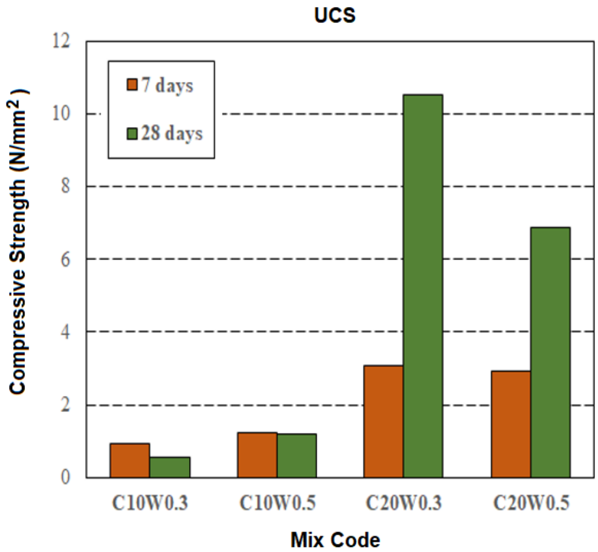

Figure 5: Effect of increasing the w/c ratio and the content of cement on the density of selected WP-concrete mixes.

4.4 Proof of concept - Growing of Grass

Figure 6 illustrates the various stages of growth of grass on concrete containing waste plastics. The grass appears healthy in terms of strength, height, and colour, suggesting that the growth environment is not toxic for growth. Future investigations will include effect on strength, durability, and performance in wide range of applications, such as sports fields and playgrounds.

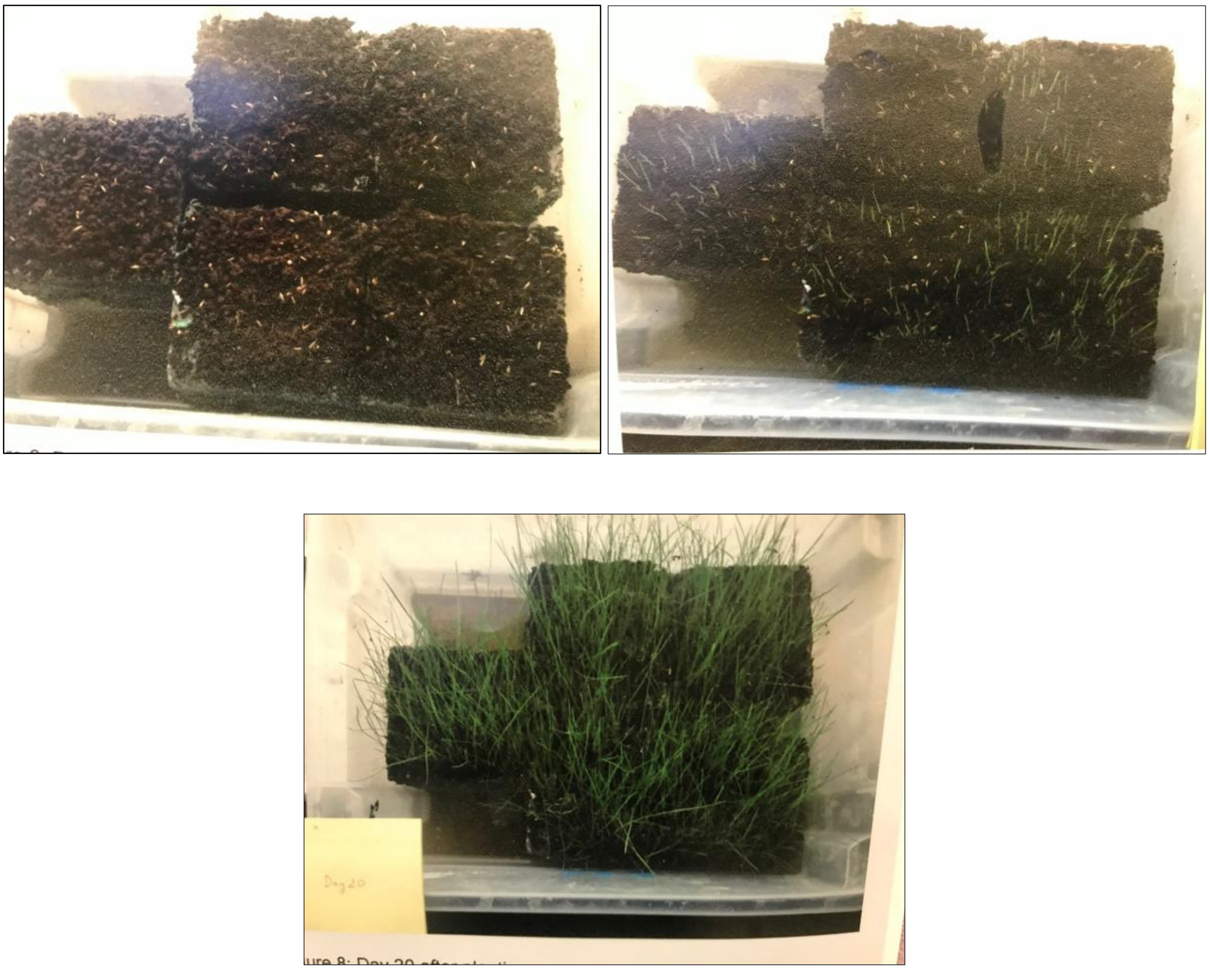

Figure 6: Grass at various stages of growth, on selected WP-concrete mixes.

5. CONCLUSIONS

The characteristics of waste plastics are varied. For use in construction, the character of the waste plastics aggregate is significant. The challenge remains on how to cope with the wide variety of shapes, textures, aggregate impact values among other variables. It is therefore likely that different approaches will have to be adopted, depending on the application in question. This paper has reviewed application of polypropylene plastic waste in concrete, where the following conclusions may be drawn:

- It has been possible to use very flexible and very flaky waste polypropylene plastics aggregates of literally no impact value in formulating concrete of low-medium strength.
- Since usable compressive strength values were achieved at both 7 and 28 days using very flaky and weak plastic aggregates, stronger waste plastic types can achieve far stronger concrete for typical requirements in building and construction.
- With waste plastics, it is possible to formulate a wide variety of concrete forms, some with unique characteristics and applications in building and construction.
- For waste plastic concrete aimed at promoting growth of grass, future investigations are recommended, to investigate among other issues the effect on strength, durability, and performance in wide range of applications, such as sports fields and playgrounds.

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Conflicts of Interest: The author states that there are no conflicts of interest in the work reported.

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