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Is 3D concrete printing low carbon? Getting it right

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Introduction: 3D concrete printing has potential to become a major concrete construction method owing to the associated benefits, such as reduced solid waste, time-savings, reduced labour costs and geometric flexibility, etc. Despite the expected benefits of the technology, the carbon impact of the binder materials used in contemporary 3D printing applications is high due to the high use cement-based materials (up to 60% of total weight). Compared to 3D print binder materials, regular concrete uses less amount of cement, for example, Grade 30 concrete usually requires about ~20% cement in the mix. This paper presents selected a few initial findings from an ongoing research investigation aiming the development of low-carbon binder materials for 3D concrete printing.

Embodied Carbon: Figure 1 presents the calculated embodied carbon values of a few 3D print concrete mixes reported in the literature together with the relevant calculated values for two normal strength grade regular concrete mixes. The embodied carbon shown in the figure were determined using the carbon factor values provided in ICE database and the relevant available literature. The results shows the embodied carbon of the 3D print mixes is 20-120% higher compared to the regular concrete.

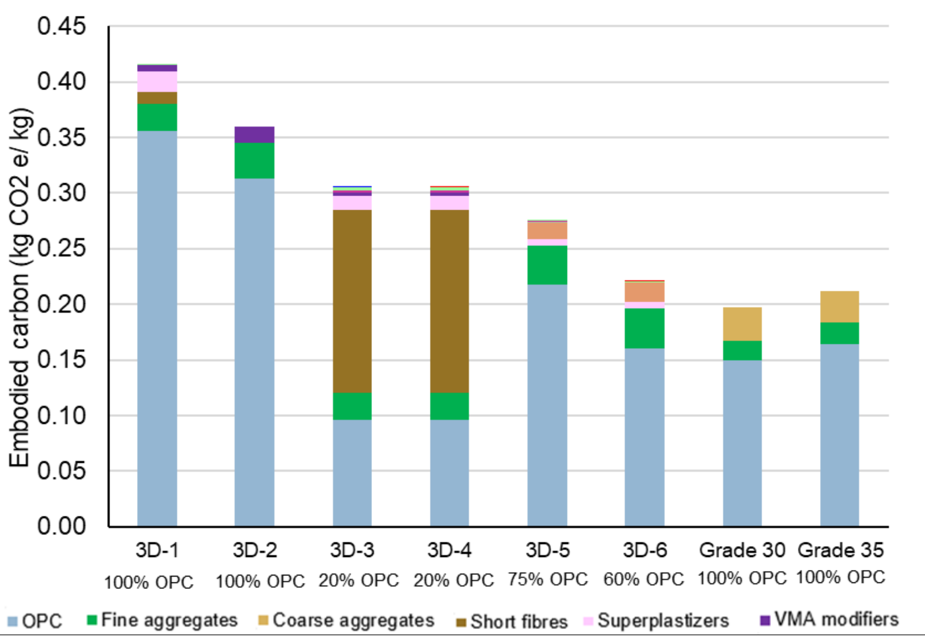

Fig 1: Embodied carbon of 3D print binders and regular concrete (Note: The embodied carbon contributions from materials such as fly ash, GGBS, silicafume and limestone are negligible compared to that of the other materials shown in Fig. 1) .

Metakaolin-based low carbon binders for 3D printing: Metakaolin ($Al2O_3.2SiO_2$) is a promising cement replacement material, due to its low processing temperature requirement (600-700ºC) together with no associated CO_2 release. On the other hand, Portland cement is processed at high temperatures (~1450 ºC) and the production of cement is associated with high amount of CO_2 release. Given Metakaolin contains high amount of aluminum (35-45% Al_2O_3), rapid hardening is expected as the reactions of aluminates are rapid compared to that of silicates. The rapid reactions are expected ensure the required rheological properties at the early stages of mixes, thereby enabling 3D printing. Metakaolin reacts with $Ca(OH)_2$, which is produced during cement hydration (see Eqs. 1 and 2), to produce strength imparting compounds such as Calcium-Silicate-Hydrates (C-S-H) and Calcium-Aluminum-Silicate-Hydrate (C-A-S-H) (see Eq. 3)

$$2[3CaO.SiO_2] \text{ (}C_3S\text{ in cement)} + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2 \quad \text{Eq (1)}$$

$$2[2CaO.SiO_2] \text{ (}C_2S\text{ in cement)} + 4H_2O \rightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2 \quad \text{Eq (2)}$$

$$2[Al2O_3.2SiO_2] + 6\,Ca(OH)_2 + 5H_2O \rightarrow 3CaO.2Al_2O_3.2SiO_2.8H_2O + 3CaO.2SiO_2.3H_2O \quad \text{Eq (3)}$$

Molar mass-based analysis of the above equations shows that up to 40% cement could be replaced with metakaolin to achieve the optimum amount of hydrated products. The expected embodied carbon saving is ~30% compared to cement-alone binders.

Conclusions: The embodied carbon impact (per unit mass) of 3D print concrete mixes are higher than that of regular concrete mixes. Use of metakaolin has potential to develop low carbon binders for 3D printing. The attainment of the required rheological properties is required to ensure the practical viability of the new binders.

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