Mechanical properties and microstructure of slag and fly ash alkali-activated lightweight concrete containing miscanthus particles

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Highlights:

- Miscanthus –based lightweight concrete was developed
- Miscanthus fibres were mixed with fly ash/slag-based alkali activated binder
- Alkali activated binder improved early age strength of miscanthus bio-based concrete

Abstract

To improve the early age strength of miscanthus-based composites, alkali-activated binders (ground granulated blast furnace slag and fly ash: AASF) were investigated against Portland cement. The impact of miscanthus content on strength development was assessed at three levels of aggregate to precursor binder mass ratio (0.27, 0.43 and 0.76). For the same aggregate to binder ratio, AASF mixes developed compressive strengths exceeding 1.3 MPa at 5% strain, seven times higher than those obtained with Portland cement , with the bulk density values measured in the range 910 -1070 kg/m^3. However, these values for vegetal concretes remain lower than those of non-vegetal concretes of similar apparent densities such as those made with polystyrene aggregates. The analysis of the microstructure of AASF composites indicated a strong interfacial transition zone, showing microstructural features that suggested the achievement of a complete reaction.

Keywords: bio-based materials; strength; microstructure; miscanthus; alkali-activated binders.

1. Introduction

Miscanthus is a high yielding, low maintenance perennial crop typically used as a biofuel across England and prevalent in Southwest with potential application in building materials [1]. Studies have been exploring miscanthus as a novel source of fibres for lightweight materials. Its use for lightweight blocks has been investigated [2,3], suggesting significantly positive environmental performance in terms of carbon capture and storage [4]. The chemical composition of miscanthus implies potential influence of its constituents on the behaviour of cementitious binders' matrices. This phenomenon occurs at the water suction phase, and results in delay and potentially inhibition of cement setting [5]. Miscanthus as a lightweight fibre in concrete is a relatively new concept, and there is currently a paucity of research on the subject. Miscanthus concrete has been considered for lightweight applications in envelopes for acoustic and thermal insulation [6,7]. Mechanical performance studies of miscanthus lightweight concrete have been carried out using natural hydraulic lime and Portland cement binders [8,9]. Alkali-activated industrial waste materials (AAIWMs), such as slag and fly ash precursors, constitute an interesting alternative to cement and lime for strength improvement. AAIWMs have recorded at least 0.73 tonnes CO_2/ tonnes of cement substitution in concrete, with added value of waste disposal reduction and reduced limestone quarrying [10]. This paper describes a research investigating the use of alkali-activated binders for early age strength improvement of miscanthus concretes.

2. Materials and methods

Plant derived aggregates were obtained from miscanthus and supplied by a farm in Somerset (UK).. Portland cement (Ce) was sourced from Tarmac UK; ground granulated blast furnace slag (GGBS) and fly ash (FA) were sourced from Ecocem (Ireland) and from a power plant in England (Drax power station), respectively. Table 1 shows the investigated mix designs. Sodium silicate solution was supplied by Fisher scientific with composition Na_2O 12.8% and SiO_2 25.5% in mass. Fig. 1 shows the initial raw materials. Compressive strength tests were conducted following a method adapted from the BS EN 12390-3:2002 standard. After curing for 28 days samples were tested using an MCC Controls hydraulic frame machine at a loading rate of 0.5N/s until failure load or excessive deformations were reached (~30%).

Fig. 1. Initial and raw materials: (a) Powder precursors and liquid alkali-activators, (b) Miscanthus particles

3. Results and discussion

3.1. Microstructural characterisation of AASF

Fig. 2 (a) shows a general overview of a fragment highlighting the interaction between miscanthus fibre and the AASF binder. A rather good interface between the binder matrix and miscanthus particles can be observed, with the latter being smooth, suggesting an alkaline degradation of surface waxes and a dissolution of hemicellulose and lignin, in contrast to the gapped interface seen in miscanthus-cement concrete [6]. The matrix grips firmly on fibrous parts of the aggregates as shown in Fig. 2(b). Similar cohesion was observed for sisal fibres in fly ash alkali-activated matrix [15]. Fig. 2(c) shows an exposed area of a miscanthus fibre, exhibiting a total lack of roughness and absence of any amorphous portions of the fibre, thus suggesting an almost complete removal of waxes, hemicellulose and lignin and the exposure of cellulose segments. Fig. 2(d) shows an area of binder, showing air voids that have formed in the binder, and smooth cavities created by undissolved fly ash particles. A number of undissolved fly ash cenospheres particles were spotted suggesting a partial reaction of precursors or a continued reaction undergoing. However, areas of homogenous geopolymerisation products were evident as well and regular cracks across the matrix area in Fig 2(d), suggesting a good degree of geopolymerisation.

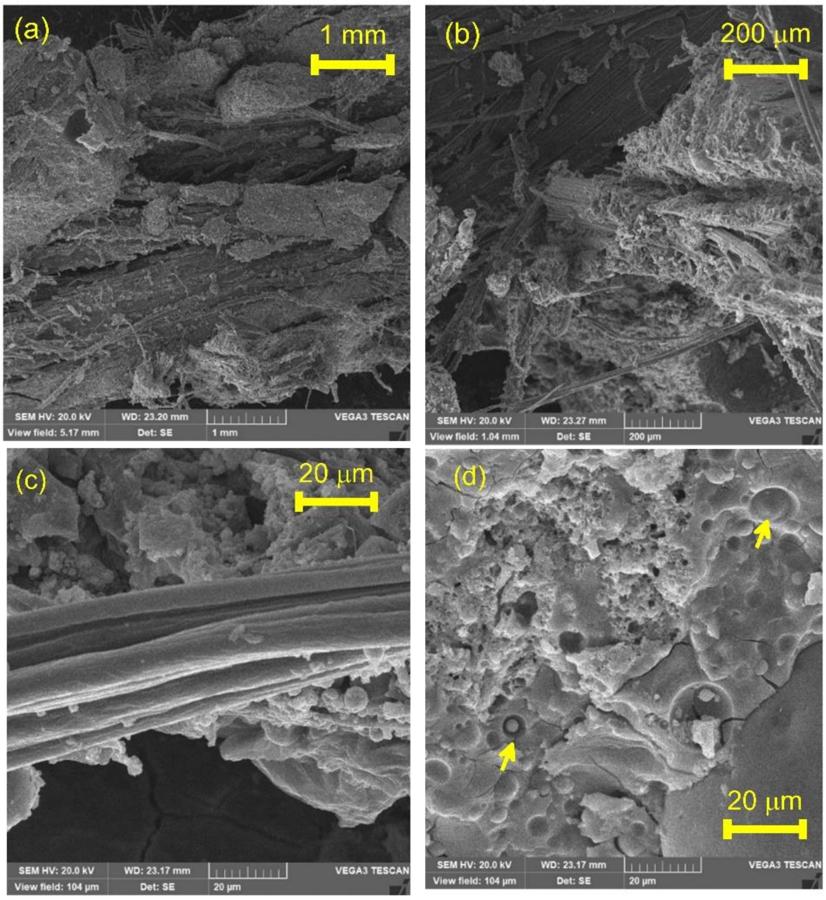

Fig. 2. SEM micrographs of the interface between miscanthus aggregates and alkali-activated binder matrix in mAASF-1.25 mix: (a) and (b) Fibre-matrix interface, (c) highlight of fibre surface with smooth areas and strong adhesion to binder, (d) Highlight of a binder system with some partially reacted fly ash particles (shown by the arrows).

3.2. Compressive behaviour of Portland cement and AASF miscanthus concrete

Fig. 3 shows the stress-strain compressive behaviour of Portland cement mix and AASF mixes. As shown in Fig. 3(a) and (b), mCe-1.25 and mAASF-1.25 samples exhibit clear failure peaks at maximum stress values around 5% strain, confirming the dominant behaviour from binder matrix, with a rather strain hardening mechanism for mCe-1.25 and a brittle failure mechanism for mAASF-1.25. However, as the miscanthus content increases in mAASF-2.0 and mAASF-2.75, strength values decrease as expected, resulting from higher aggregate to paste ratio, as miscanthus provides little contribution to strength. There is a shift of failure mechanism towards ductile strain-hardening as the fibre content increases. Fig. 4 shows the bulk density and compressive strength values of samples after 28 days. Comparing the compressive strength of mCe-1.25 and mAASF-1.25 samples (Fig. 4.a), the latter show an average compressive strength of ~1316 kPa, i.e., seven times higher than that of mCe-1.25 samples (184 kPa). Fly ash and GGBS alkali-activated vegetal concretes have comparable compressive strength values, ranging from 1.9 to 2.1 MPa for densities ranging from 906.7 to 1063.3 kg/m3 [11]. Nonetheless, when compared to other non-vegetal lightweight concretes, such as those containing extruded polystyrene [12], these strength values remain relatively low. The low strength values recorded for mCe-1.25 samples suggest possible influence of lignocellulosic leachates from miscanthus fibres, which prevent the Portland cement from reaching its typical characteristic strength [13]. Moreover, the average apparent density of mAASF-1.25 samples is ~28% higher than that of mCe-1.25 samples (Fig 3.b). This difference was expected as additional hydration and geopolymerisation products in AASF mixes form denser CASH structures that contribute to enhance the density of the matrix and that of concretes [14].

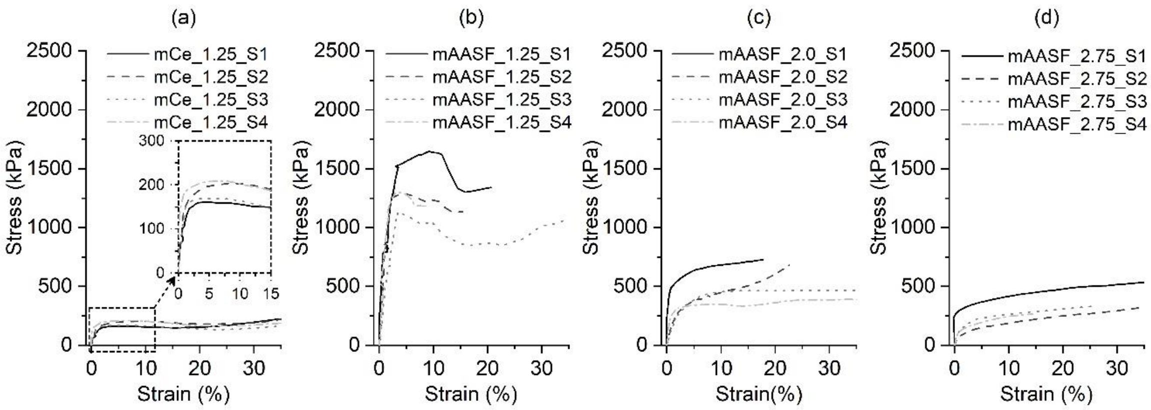

Fig. 3. The mechanical performance of miscanthus concrete with different binders: (a) mCe-1.25: Portland cement, (b), (c) and (d) mAASF-1.25, mAASF-2.0 and mAASF-2.75, resp. S1-4 stands to series of samples in batches 1 to 4 of the same mix.

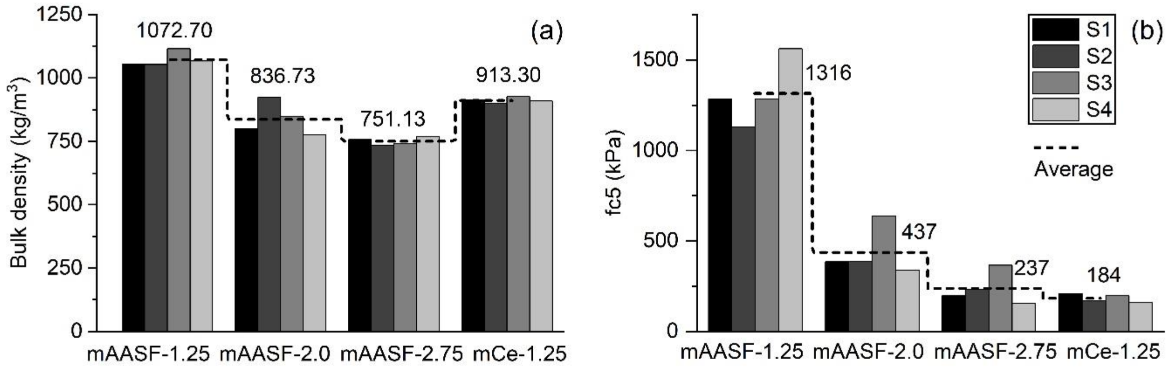

Fig. 4. (a) Bulk density and (b) strength at 5% strain of miscanthus concrete in cement and AASF binders. S1-4 stands to series of samples in batches 1 to 4 of the same mix.

4. Conclusion

The possibility of producing a lightweight fibre-based concrete using alkali-activated slag and fly ash binders, incorporating miscanthus fibres, and the effects of miscanthus content on compressive strength development were investigated. The microstructure of the interface between the alkali-activated matrix and miscanthus particles was assessed using SEM. The results showed that alkali activated slag-fly ash binder exhibited compressive strength values 7 times higher than that of cement-miscanthus mixes for comparable aggregate content. The microstructure of alkali-activated binders in the presence of miscanthus aggregates showed a rather strong cohesion between the aggregates and the reacted matrix, as opposed to miscanthus-cement gapped adhesion, even though some partially reacted fly ash particles were observed.

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