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What is the potential of alternatives to Portland cement in respect to environmental impact, engineering suitability & future use?

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ABSTRACT

Concern over the impact of anthropogenic CO_2 emissions on the global climate has increased in recent years due to growth in global warming awareness. The manufacture of Portland cement (PC, or CEM 1 in European Standards) accounts for 5-7% CO_2 of global emissions (1), which are responsible for global warming. Alternative types of cement can minimise CO_2 emission and may become full or partial alternatives to PC in the construction industry. This paper focuses on alternative cements as a mechanism to minimise CO_2 emissions. However, there is a need for a centralised knowledge source (i.e. guidance documents) that would enable a concrete professional to determine the most appropriate use of an alternative cement. To address this shortfall, the most likely alternative cements were considered as part of a literature review, under the main headings of environmental impact, engineering suitability and future use. Furthermore, this was supported by discussions with representatives of industry, and the subsequent summary table is a useful tool to compare the alternative cements. A selection process is also included, which is in the form of a decision-making flow chart that guides the reader through to the appropriate alternative cement based on responses to the questions asked. However, there are limitations to the decision-making flow chart, as out of the five alternative cements reviewed, only two types (AAM/geopolymers & calcined clay) are presently being offered in the UK by the cement/concrete producers that were contacted. Furthermore, only calcined clay has been covered within the codes i.e. BS EN 197-1 and 5.

This paper, summarising work carried out for an MSc dissertation, provides a small step in the selection process by attempting to bring together the key aspects of the most likely alternative cements at the present time. It aims to aid the civil engineer and stakeholders to determine the most appropriate alternative cement type, and at worst ask further questions. Ultimately, the new alternative cements need to be positioned at the centre of a new and necessary transition from today's PC to the developing cements of the future.

Keywords: Alternative Cements, Civil Engineering, Environment, Sustainable, Future.

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1 Introduction

Portland cement (PC) is a widely used commodity, second only to water in the world, where approximately four billion tonnes of PC are produced on an annual basis. It is one of humankind's most ubiquitous, inexpensive, and useful materials. Producing clinker, the primary ingredient in cement, requires heating limestone to 1450°C. Burning fossil fuels is the main method used to provide energy for the process, accounting for 40-50% of emissions; additionally, limestone decomposes upon heating, accounting for the remaining 50-60%. These emissions account for 5-7% of global CO_2 emissions (though in the UK this value is about 1%), so its manufacture is of primary importance in any global decarbonisation process. Efforts to minimise the energy related emissions include reducing the dependence on fossil fuels, the use of carbon capture and storage for cement plants and minimising the use of PC with alternative cements (1).

To address the adverse effects of Carbon dioxide's contribution, the concrete industry and its associated partners must be able to develop a unified strategy that targets a net zero CO_2 future within realistic timescales. The current targets are net zero CO_2 emissions by 2050 and an intermediate target of at least 55% of 1990 levels by 2030 (2). To achieve this, organisations within the concrete sector have produced roadmaps as an approach to identify key areas. These key areas will address the collective goal of limiting global warming to 2°C and pursuing efforts to limit it to 1.5°C in accordance with the Paris Agreement (3).

The GCCA roadmap considers the following key areas to achieve a net zero future (in order of their greatest contribution to CO_2 emissions savings by 2050) (4):

- Carbon capture and utilisation/storage (36%);
- Efficiency in design and construction (22%);
- Savings in clinker production (11%);
- Efficiency in concrete production (11%);
- Savings in cement binders (9% - i.e. PC substitution/alternatives to PC);
- CO_2 sink re-carbonation (6%);
- Decarbonation of electricity (5%).

Thereby the GCCA shows that the expected reduction in CO_2 emissions by 2050, using alternatives to Portland clinker and Portland cement substitution, would be 9%; the MPA has stated 12% (5), and the figure stated by CEMBUREAU is around 9% (6).

This paper will focus specifically on alternative cements, i.e. minimising/negating PC contribution within the concrete mix. However, there are numerous novel or new cements that are generally non-PC and hence it will be only the commercially "realistic" alternative cements identified that will be considered within the paper.

The main purpose of this paper is to provide the civil engineer/stakeholders with the necessary key information to determine the most appropriate alternative cement to PC with respect to specific properties.

2 Summary of Alternative Cements

This summary table shows the properties of the alternative cements with respect to Portland cement CEM I. The information within the summary table is taken from the literature review and discussions with industry, fully referenced in the source dissertation.

Table 1 - Showing the Properties of Alternative Cements in Respect to Portland Cement CEM I

Alternative Cement Type Property	***Calcium Sulfoaluminate***	***AAM/Geopolymers***	***Magnesium Carbonate***	***Magnesium Silicate***	***Calcined Clay***
Environmental – CO_2	Between 25-50% CO_2 reduction compared to CEM I (PC).	Between 20 - 80% CO_2 reduction compared to CEM I (PC).	Between 40 - 50% CO_2 reduction compared to CEM I (PC) when fully sequestered during the curing process.	Potential to be CO_2 negative as the CO_2 generated into the process is recycled back. Magnesium silicates are intrinsically CO_2 free.	Circa 30% CO_2 reduction compared to CEM I (PC).
Compression & Flexural Strength	Early strengths are higher. Long-term strength can exceed PC.	Higher strengths. Higher early age strengths.	Compressive (reduced by 10% - with 5% MgO and reduced by 30% with 20% MgO) and flexural strength decrease when added.	Compressive strengths of over $40N/mm^2$ at 28 days has been achieved. Compressive strength, tensile strength and modulus of elasticity are slightly lower than PC.	Comparable 28-day compressive strength. 15% replacement of PC showed the highest strength. Higher flexural strength. Early age strength development is lower than PC.
Reinforcement Suitability (passivation)	Protection has been confirmed comparable to PC; however the alkalinity is	Some studies have shown that reinforcement is	Due to a relatively low pH (9.9 to 10.5) passivation was not formed on the	In early research stage, hence no conclusions can be	Comparable to PC, however longer-term validation is required.

	circa 1 pH unit lower (circa between 10 and 11.5). Divergent statements have been noted in the literature and this is likely to be due to the composition of the CSA.	protected and has superior pH conditions than PC binders. However, providing an alkaline environment over the long term has not been ascertained.	embedded rebar surface. Corrosion rates of circa two orders of magnitude higher than PC. This issue would have to be overcome for a wider utilisation of the materials in construction.	drawn at the present time.	
Carbonation Resistance	Generally lower to similar. High-strength CSA has excellent resistance.	Poor to acceptable carbonation rates, but highly dependent on material used. Resistance is lower than PC.	Carbonation depth increases with the use of reactive MgO to the detriment of PC. This increase can reach up to 400% for ratios of 20% MgO.	In early research stage, hence no conclusions can be drawn at the present time. However, it has been reported that they have a higher permeability and porosity than PC.	Adequate protection if PC content is at least 60%.
Chloride Resistance	Lower chloride penetration resistance to PC, but still good.	Higher resistance than PC.	No information identified. However, this is probably due to the fact that reinforcement should not be used i.e. poor passivation.	In early research stage, hence no conclusions can be drawn at the present time. However, it has been reported that they have a higher permeability and porosity than PC.	Higher resistance and the corrosion products were less expansive and hence less destructive to concrete.
Freeze-Thaw Resistance	No information identified.	Higher resistance.	Minimal effect on the freeze-thaw resistance.	In early research stage, hence no conclusions can be drawn at the present time. However, it has been reported that they have a higher permeability and porosity than PC.	Only concrete with metakaolin showed satisfactory performance.

Sulfate Resistance	Good to excellent resistance. However higher diffusion coefficient in Cl-rich environments.	Higher resistance than PC.	Excellent resistance.	In early research stage, hence no conclusions can be drawn at the present time. However, it has been reported that they have a higher permeability and porosity than PC.	Higher resistance than PC.
Shrinkage	Lower to similar drying shrinkage.	AAM- Greater shrinkage and microcracking. However, the use of an SRA can reduce the shrinkage. Geopolymer – 80% lower shrinkage than PC.	Shrinkage is always lower with MgO.	In early research stage, hence no conclusions can be drawn at the present time.	Total shrinkage was lower/similar.
Workability	Far more sensitive to temperature, w/c ratios, pozzolan replacements. Replacing with no PC may cause short setting times. Blending with PC may offer advantages e.g. expansion and setting time, passivation, and porosity. Admixtures must be added to reduce setting rate	Faster setting time. Hence due cognisance must be taken to ensure workability is not compromised i.e. by the use of suitable admixtures.	No information identified.	In early research stage, hence no conclusions can be drawn at the present time.	Worse workability – large quantities of superplasticizers required.
Admixtures	No information identified.	PC admixtures are not effective/limited in enhancing flow behaviour, hence a higher w/c ratio. Further research is required.	No information identified.	In early research stage, hence no conclusions can be drawn at the present time.	See “Workability” above.
Alkali Aggregate Reaction	Low alkalinity appears to be favourable.	Unknown. The presence of higher levels of alkali	No information identified.	In early research stage, hence no conclusions can be	Advantages of mitigating against AAR.

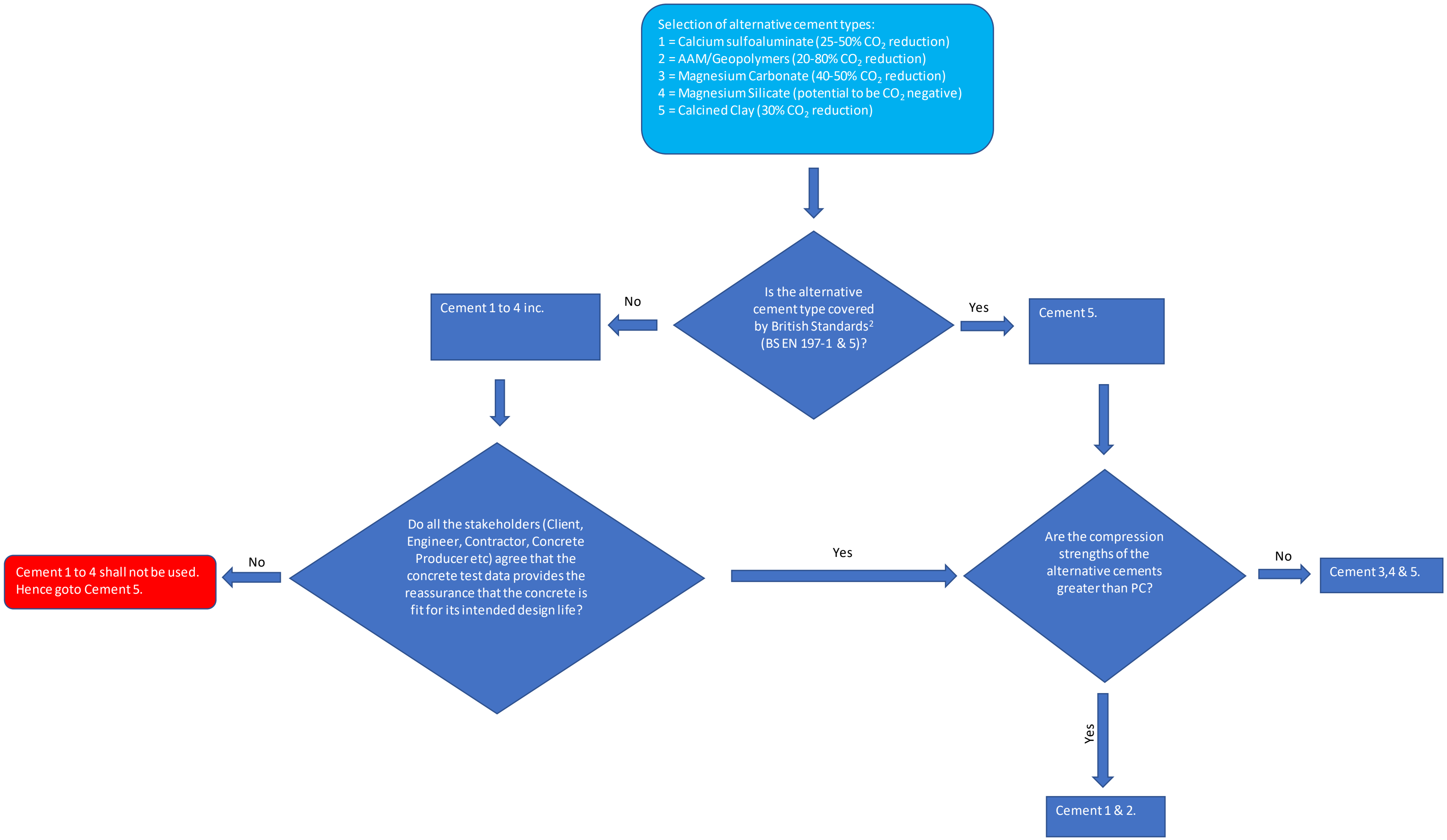
		elements ameliorates the chance of AAR occurring.		drawn at the present time.	
Acid Attack	No information identified.	Higher resistance.	No information identified.	In early research stage, hence no conclusions can be drawn at the present time.	No information identified.
Fire Resistance	No information identified.	Higher performance.	Conflicting report of high fire resistance and concerns of the fire resistance.	In early research stage, hence no conclusions can be drawn at the present time.	No information identified.
Efflorescence	No information identified.	Prone to formation.	No information identified.	In early research stage, hence no conclusions can be drawn at the present time.	No information identified.
Applications	China – bridges, leakage and seepage prevention, concrete pipes, precast concrete (beams and columns), prestressed concrete elements, waterproof layers, glass fibre reinforced cement products, low temperature construction and shotcrete. Hazardous waste encapsulation. Airport runways. Marine application.	Civil engineering, automotive and aerospace industries, non-ferrous foundries and metallurgical industries, waste immobilisation, art and decoration and retrofitting of buildings. High performance structural purposes.	Growing interest as a cement binder, but it is generally used in a range of applications within the pharmaceutical, agricultural, and paper industries. Used in ground improvement and stabilisation of contaminated waste. Due to high cost it may be restricted to specialist applications such as stabilisation of high sulfate bearing soils. Used for rapid repairs to damaged concrete pavements and runways. Used also in refractories.	No information identified.	Similar to other general use cement types. Construction of residential buildings. High - performance binder system for concreting applications, especially in marine/chloride environments.

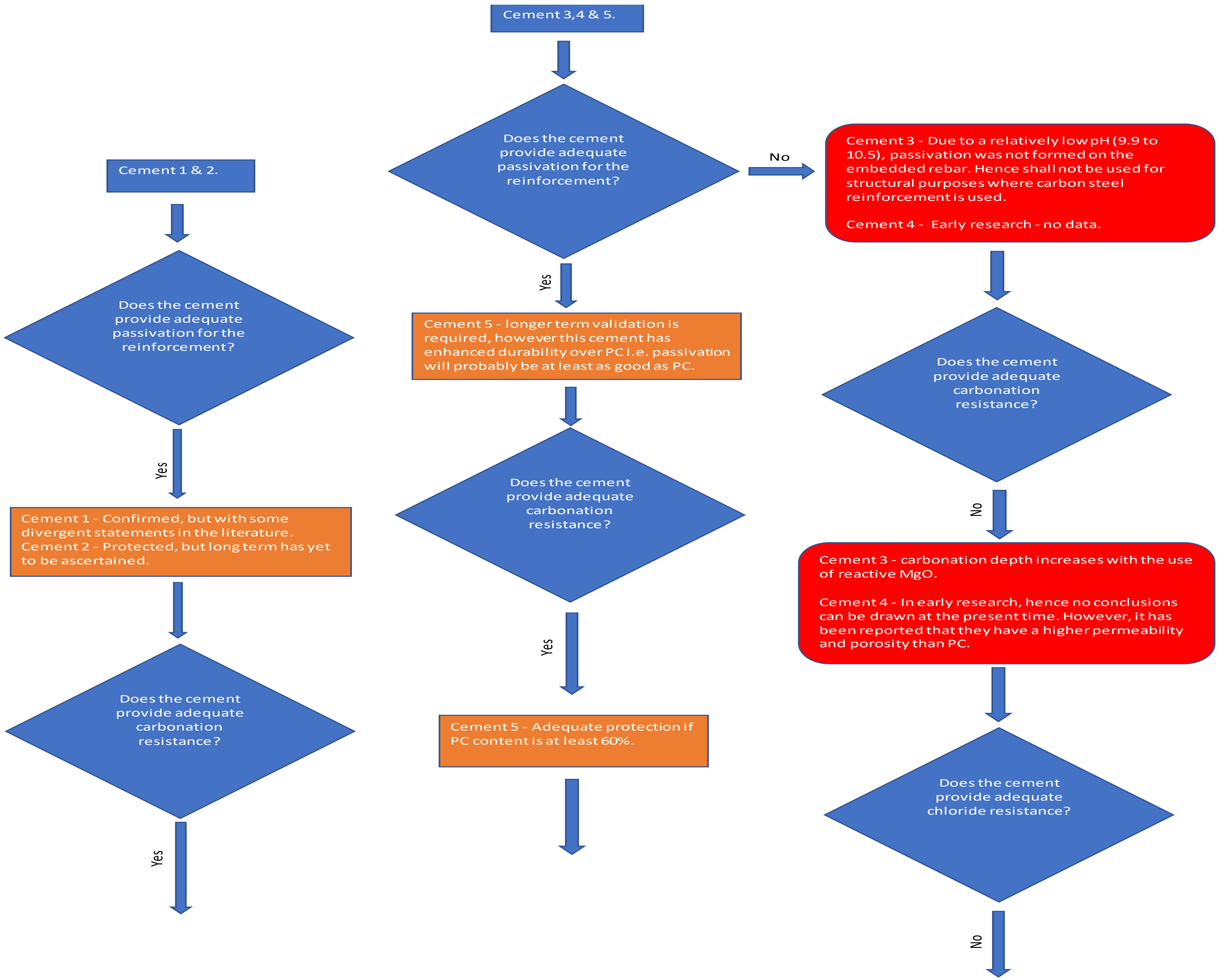
Future Use	From leading as an alternative cement, to no future as a leading cement. Global availability of raw materials is limited. More research required on the durability.	Greater understanding of durability issues is required. Lack of international standards.	Majority of deposits are located in China and North Korea i.e. low availability at a global scale. The UK market has a lack of significant magnesite deposits. It is likely that MgO cements will only complement PC in niche markets.	Magnesium Silicates are abundant worldwide, however are not uniformly distributed. They are less so in the UK and deposits tend to be located in environmentally sensitive areas. Magnesium Silicates are presently academic and further research is needed	Clay is widely spread and has different mineralogical compositions, and these variations must need to be considered. Hence it is important to fully understand and characterise the clay available before designing the extraction, pre-processing, and calcination processes.
Cement Standard	Not recognised by current British Standards.	Not recognised by current British Standards.	Not recognised by current British Standards.	Not recognised by current British Standards.	Allowed in the European Standard EN 197-5 up to 50% replacement for a CEMII/C-M, and EN 197-1 allows clinker replacement levels of up to 20% and 35% for CEM II/A-M and CEM II/B-M respectively.
Concrete Manufacturers/Organisations Comments & Cements on Offer	*MPA* – Their will be a lack of interest in testing these cements if SCMs are available. *Hanson* – don't produce CSA, but their parent company does in Italy.	*MPA* – UK organisations are presently undertaking research into AAM, however will remain as a "niche" as no plans to develop generic guidance for their application (BS 8500)	*MPA* – These cements will continue to be used in niche applications i.e. not general purpose. No cements presently on offer.	*MPA* – These cements will continue to be used in niche applications i.e. not general purpose. No cements presently on offer.	*Cementir Holdings* – offer a calcined clay concrete - FUTURECEM™ is included in EN 197-5 as CEMII/C-M with only 50% clinker. *MPA* – recently commenced with a

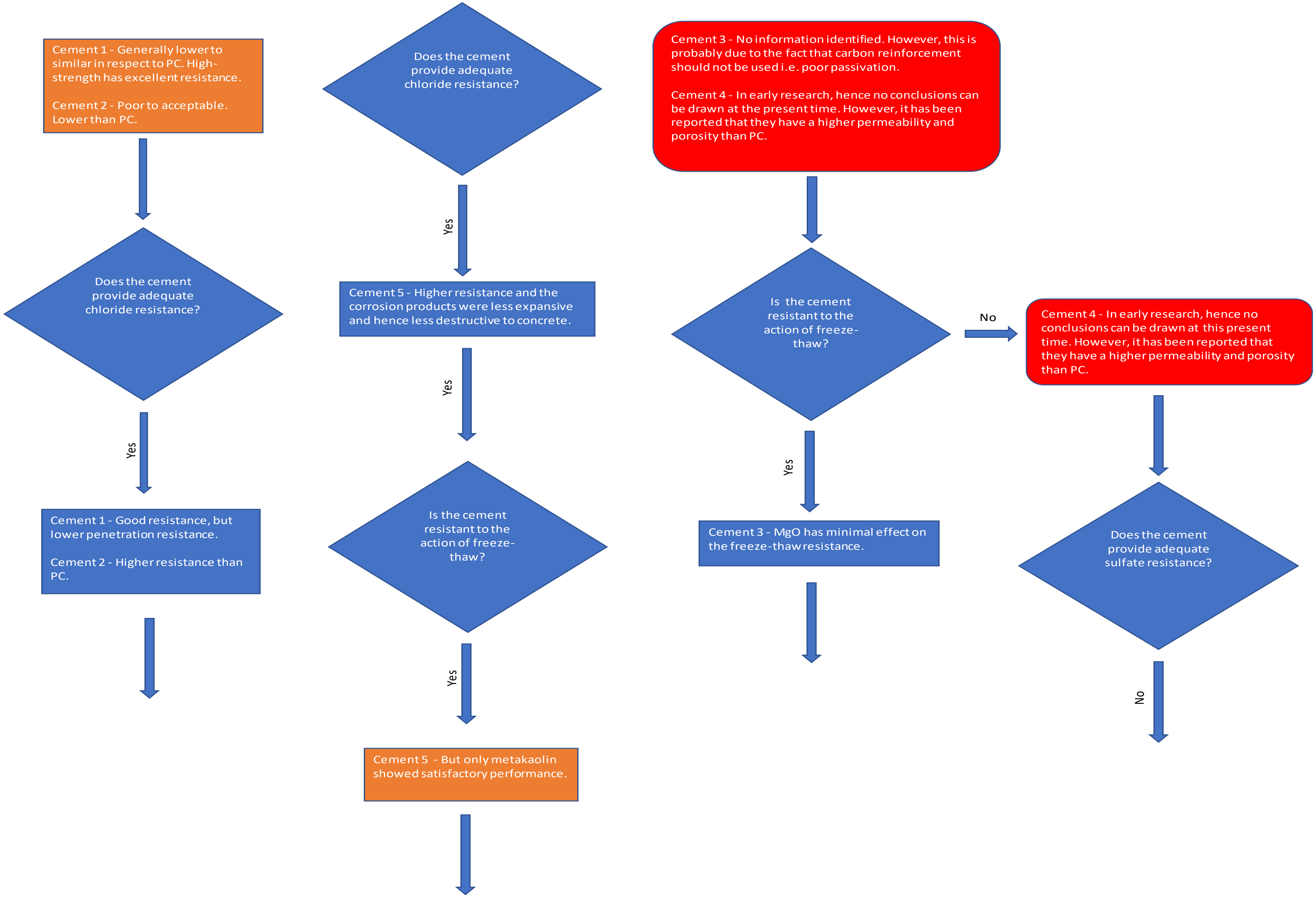
		Cemex – offer a geopolymer concrete – Vertua ultra zero. Not recognised by current BS. *Hanson* – Don't offer AAM. *Breedon* – completed a series of full-scale trials with the geopolymer- Earth Friendly Concrete (EFC®). *Aggregate Industries* – offer an AAM – ECOPact Max as part of ECOPact range. Ecocem – offer an AAM- Ecocem Ultra.			project on testing calcined clay cements. *Hanson* – presently exploring if any of the non-kaolinitic clay sources in the UK have the potential for calcination.

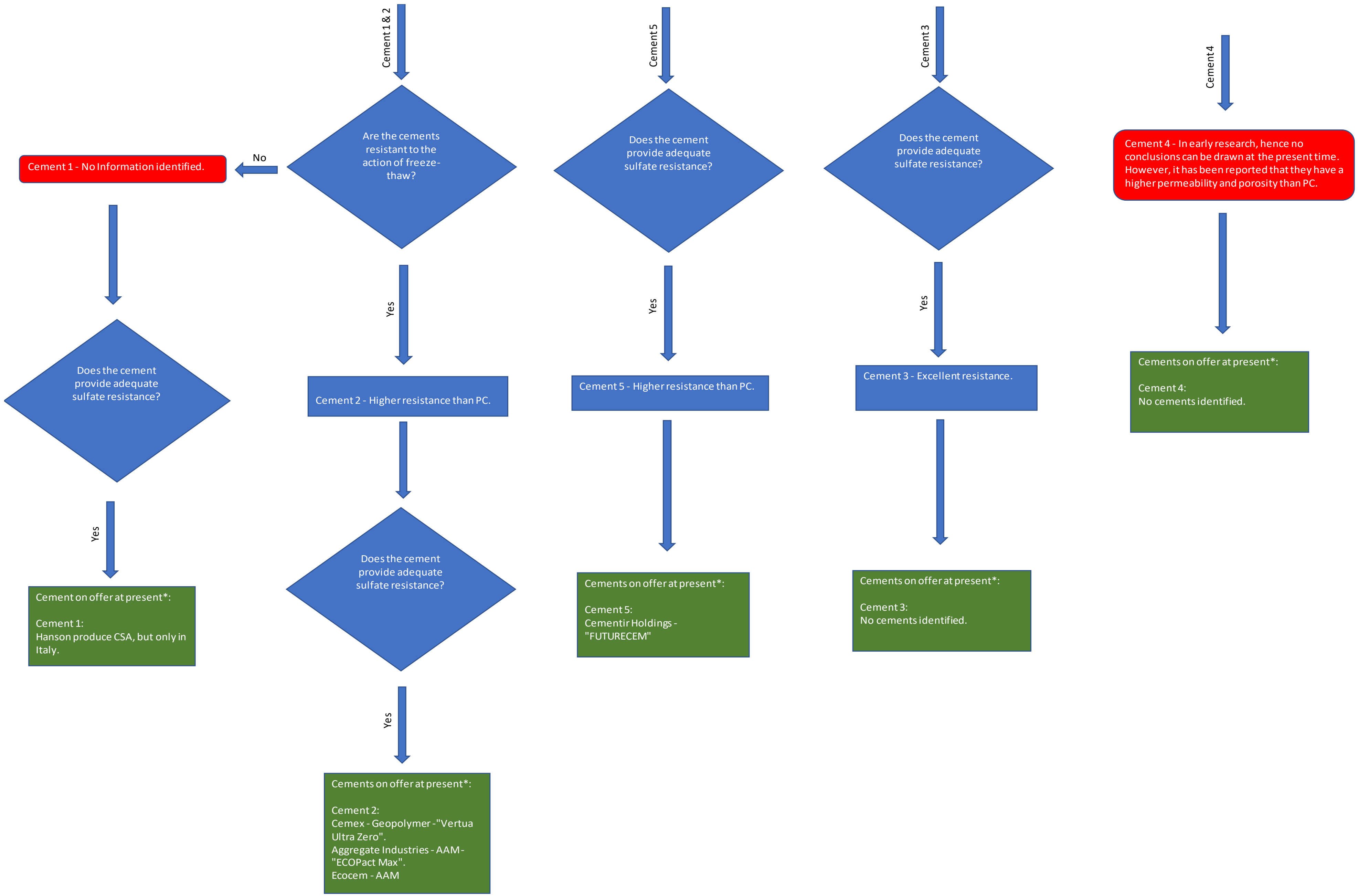
3 Decision Making Flow Chart for Selection of Alternative Cements

A decision-making flow chart tool has been produced to aid the civil engineer/stakeholder in determining the most appropriate alternative cement based on the responses to the questions asked. The development of the flow chart is based on the findings of the literature review and discussions with industry.




Cement 1 & 2.
Does the cement provide adequate passivation for the reinforcement?
Yes
Cement 1 - Confirmed, but with some divergent statements in the literature.
Cement 2 - Protected, but long term has yet to be ascertained.
Does the cement provide adequate carbonation resistance?
Yes
Cement 3,4 & 5.
Does the cement provide adequate passivation for the reinforcement?
No
Yes
Cement 5 - longer term validation is required, however this cement has enhanced durability over PC i.e. passivation will probably be at least as good as PC.
Does the cement provide adequate carbonation resistance?
Yes
Cement 5 - Adequate protection if PC content is at least 60%.
Cement 3 - Due to a relatively low pH (9.9 to 10.5), passivation was not formed on the embedded rebar. Hence shall not be used for structural purposes where carbon steel reinforcement is used.
Cement 4 - Early research - no data.
Does the cement provide adequate carbonation resistance?
No
Cement 3 - carbonation depth increases with the use of reactive MgO.
Cement 4 - In early research, hence no conclusions can be drawn at the present time. However, it has been reported that they have a higher permeability and porosity than PC.
Does the cement provide adequate chloride resistance?
No


Cement 1 - Generally lower to similar in respect to PC. High-strength has excellent resistance.
Cement 2 - Poor to acceptable. Lower than PC.
Does the cement provide adequate chloride resistance?
Yes
Cement 1 - Good resistance, but lower penetration resistance.
Cement 2 - Higher resistance than PC.
Does the cement provide adequate chloride resistance?
Yes
Cement 5 - Higher resistance and the corrosion products were less expansive and hence less destructive to concrete.
Yes
Is the cement resistant to the action of freeze-thaw?
Yes
Cement 5 - But only metakaolin showed satisfactory performance.
Cement 3 - No information identified. However, this is probably due to the fact that carbon reinforcement should not be used i.e. poor passivation.
Cement 4 - In early research, hence no conclusions can be drawn at the present time. However, it has been reported that they have a higher permeability and porosity than PC.
Is the cement resistant to the action of freeze-thaw?
Yes
Cement 3 - MgO has minimal effect on the freeze-thaw resistance.
No
Cement 4 - In early research, hence no conclusions can be drawn at this present time. However, it has been reported that they have a higher permeability and porosity than PC.
Does the cement provide adequate sulfate resistance?
No



Flow Chart Notes

1. *Colour codes - "Red "Boxes" - warning response, "Orange Boxes" - caution response, "Blue Boxes" - question/response, "Green Boxes" - cements on offer at present.*
2. *It is expected that BS 8500 will be revised and published in 2022 and will include the cements in BS EN 197-5.*
3. ** denotes from cement manufacturers contacted.*

4 Discussions

What are the prospects for the use of new alternative cements in general?

The prospects for the use of alternative cements in general for the future will probably become a necessity due to the lack and quality of SCMs. Stephane Plisson (CEMEX) has stated that they along with other companies do not have sufficient supply in the UK of PFA and hence the shortfall of PFA must be imported. This is supported by Shi et al (7) stating the high demand of SCMs, such as silica fume, fly ash and GGBS, which is further accentuated as the global production of some of these industrial by-products may significantly decrease soon. Furthermore, the supply of traditional SCMs (fly ash or GGBS) are limited to some areas of the world (7). This raises the question of how sustainable the current SCMs are and what if any are going to replace them and the need to expedite the alternative cements for greater coverage within the world. Nina Cardinal (Hanson) has reported that rather than focusing on new clinker products, the focus is more on alternative SCMs, in particular on calcined clays, exploring whether any of the non-kaolonitic clay sources in the UK have potential for calcination. Calcined clays are gaining in popularity in countries where kaolinitic clays are readily available. Furthermore, the greater use of limestone fines as a SCM to PC should be considered and the use of other cement types with less PC.

New alternative types of cement being used universally is unlikely due to the various factors that are stated below:

- Cost parity;
- Scalability of the production process to produce the necessary volumes;
- Availability of raw materials;
- The geographic logistics of transporting the source materials to the concrete producer.
- Ease of use;
- Suitable physical/chemical properties;
- Durability performance;
- Mechanical strength performance;
- Issue with products/leachates;
- Robustness with respect to temperature/humidity/admixtures;
- Full understanding of the mineralogy of the mineral source;
- Confidence with the long-term properties to ensure that the design life is not compromised. This assurance can be gained by historical usage of the cements for projects across the world and by testing at universities and other UKAS testing facilities as validation of performance. This can be enhanced with the involvement of all the stakeholders (industry, consultants, and academia) to develop the design standards and codes that will place alternative cements on parity as PC, in terms of an acceptable cement type. It is envisaged that the consultation will need to be worldwide to accelerate the use of these new cements (8);
- Lack of experience of civil engineers, concrete producers, and concrete operatives on knowing what issues they may encounter that may be different from traditional concretes i.e. the unknown;
- Stakeholder acceptance;
- Suitability in certain engineering applications and environments;
- Use of existing plant for processing.

Alternative cements are more likely to be geographically constrained to suit the proximity of materials and existing plants. Of the alternative cements considered in this paper the front runners are AAM/geopolymers and calcined clay cements. The former is offered by CEMEX and Aggregate Industries, with Breedon currently undertaking trials, and the latter is being offered by Cementir Holdings, with MPA and Hanson undertaking trials and exploration respectively. The other alternative cements considered in this paper do not appear to be considered as of any interest by the UK concrete industry.

From a civil engineering perspective, the fundamental design attributes of reinforced concrete are its strength and durability. Hence, for structural applications these are the two most important aspects from a design engineers' perspective. Therefore, from the research undertaken in terms of structural use the most appropriate choice of the alternative cements is calcined clay followed by AAM/geopolymers, essentially as there is a code in place for calcined clays. However, both alternative cements satisfy the criteria on strength, but durability aspects such as carbonation is a potential issue for both. Furthermore, calcined clay using metakaolin showed satisfactory freeze-thaw performance as opposed to higher resistance for AAM/geopolymers. It should also be noted that passivation over the long term has not been validated for both cement types, which is a concern. Hence, it should be remembered that circa 50% of Europe's annual construction budget is spent on refurbishment and remediation of existing structures (9), and this situation does not want to be exacerbated by using unsubstantiated types of cement.

Should we be focusing on new alternative cements, or making a better choice out of "normal cements", or both?

In the short term, we should be selecting the most appropriate "normal cements" to minimise CO_2 emissions, but not at the expense of their performance (strength and durability etc). It has been stated by Colum McCague of the MPA that CEM I ("normal cements") is still being used, but in relatively low volumes. Furthermore, CEM I is unlikely to be specified for reinforced concrete structures, as the exposure classes require a different cement type to a pure CEM I. Short-term gains in reducing CO_2 emissions can be made from "normal cements" by (10):

- Using less concrete for the same function (optimise the design);
- Less use of carbonate materials;
- Use waste materials to replace cement;
- Improving the processing energy efficiency;
- Optimise existing concrete;
- Carrying out the appropriate maintenance for existing structures.

Furthermore, the alternative cements should run alongside the "normal cements" in the short term and become the front runners in the long term once the assurance is in place, or as far as reasonably practicable as it can be.

There should be more dialogue between the civil engineer and the concrete producer to identify the most suitable concrete for the application. Furthermore, it would be useful for BS 8500 and/or the concrete supplier to show how much CO_2 emissions are generated for each cement type, and it should be stated on the same basis, i.e. compare "apples with apples".

What are the major barriers to adoption of new alternative cements more widely and in specific cases, and how might these be overcome?

The higher financial costs are an obstacle for CSA cements (11), AAM (12), MgO (13), except for calcined clay cements which are lower than for PC (14). Notwithstanding, the financial costs the fundamental lack of guidance and codes will be the "blocker" for the take up of these alternative cements as expressed by all the concrete producers that were contacted. The only alternative cement that has been included in the codes is calcined clay, which has now been included in BS EN 197-1 and 5. It is possible that the financial costs would reduce with increased demand for alternative cements.

The two front runners of the alternative cements are AAM/geopolymers and calcined clay, which both require further understanding of durability issues (15) and with AAM/geopolymers requiring acceptance into the codes and standards (12). This can be addressed by research and involving the committee members at an early stage to expedite the compilation of the codes and standards. However, the concrete industry needs a programme where knowledge can be targeted and disseminated to all the stakeholders. This knowledge transfer can be achieved by carrying out webinars, seminars and, training days. Without, the appropriate education it will be difficult to move forward with these alternative cements as a worthwhile successor to PC.

It is important to recognise that clay used for calcined clay cement is widely spread geographically and has different mineralogical compositions, and these variations must need to be considered (16). Hence it is of paramount importance to fully understand and characterise the clay available before designing the extraction, pre-processing, and calcination processes (17).

There is a high level of conservativism in the construction industry, and risk aversion towards new products, especially without associated codes of practice or standards. This is evidently clear, particularly in highly regulated industries e.g. nuclear and petrochemical etc. The construction profession is driven by processes and procedures where a jump of faith into the unknown is rarely taken without significant risk mitigation. The construction industry at heart is risk adverse and rightly so, as inappropriate actions could have serious implications to people and the wider environment. Furthermore, not all risks can be eliminated or even identified as things are either overlooked or are simply unknown according to our current understanding. Therefore, the construction industry must remain vigilant and carry out appropriate research on any new products and must not miss steps to satisfy a specific flavour of the month at the expense of the other i.e. a holistic approach in the selection of the cement type is desirable.

Once these issues have been resolved by research involving industry and sharing with the world-wide concrete community, the construction industry will be in a position where the alternative cements have a chance to make a better future for all. The dissertation on which this paper is based provides a small step in this long process by attempting to bring together the key aspects of the alternative cements that are most likely at the present time. Hopefully this will aid the civil engineer and other stakeholders to determine the most appropriate alternative cement type and at least ask further questions. Ultimately, the new alternative cements need to be positioned at the centre of a new and necessary transition from today's PC to the new cements of the future, to achieve the target of net zero emissions by 2050.

5 Conclusion

The objectives were carried out and the aims of this study have been met which has enabled a method of selecting the most appropriate alternative cement. This has been achieved using the combination of the current research and discussions with the concrete industry. The results of which enabled the production of the summary table and a decision-making flow chart. The former provides a useful summary comparison of the alternative cement type, and the latter provides a means of selecting the most appropriate alternative cement type. However, the decision-making flow chart does have limitations in the final determination of the cement due to the lack of data and the lack of alternative cements on offer for the UK market. Notwithstanding this, it still provides a logical approach as a means for the selection of the most appropriate alternative cement based on the present information identified. It is envisaged that once more data comes through the summary table and the decision-making flow chart can be updated.

This study reviewed five alternative cements, with only two types (AAM/geopolymers & calcined clay) that are presently being offered in the UK from the cement/concrete producers that were contacted. Furthermore, only calcined clay has been covered within the codes i.e., BS EN 197-1 and 5. However, the use of calcium sulfoaluminate could be used in projects specific to China/North Korea, as could magnesium carbonate subject to following the national codes. The use of magnesium silicate appears to be in its infancy where more research is needed in key areas of its properties before it can be considered as a realistic potential alternative to PC.

It is clear from the research and discussions with industry, that the concrete industry is taking CO_2 reduction seriously with roadmaps in place to target a net zero CO_2 emissions by 2050. The concrete/cement producers in the UK are producing alternative cements such as AAM/geopolymers and calcined clay which help to ameliorate the reduction in CO_2 emissions.

This can now be used as a tool for future projects that will enable the civil engineer/stakeholder to support the client's needs in meeting the governments carbon net-zero ambitions for 2050. Whereby the findings of this paper can be utilised to determine the most appropriate realistic alternative cement, as a substitute for the current cements used by the client. This will hopefully enable a workable solution for a particular design application that reduces CO_2 emissions without comprising the concretes design life.

Furthermore, the research has identified areas of where information (see Table 1) has not been identified or conclusions cannot be made. Therefore, further investigation is required to attempt to solve these unknowns. Ultimately, we need the assurance from the codes and standards etc., that will provide the concrete industry with the impetus to take these alternative cements on par with PC.

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