Installation Research Projects (Call identifier: UIP-05-2017)

ALTERNATIVE BINDERS FOR CONCRETE: understanding microstructure to predict durability

ABC

Current practice

Concrete is the world's most used construction material (and second used material in general after water), with over 25 billion tons of concrete used worldwide each year [1]. Traditional concrete industry is based on linear model, *i.e.* during production large amount of non-renewable resources is utilised and significant emissions caused, and at the end of the service life energy is used for demolition with generation of waste and emission. **Cement alone contributes to approximately 96% of the carbon footprint of concrete, and 85% of the embodied energy** [2]. In 2015, the total mass of cement produced was 4,6 billion tonnes [3], [4]. This is equivalent to about 626 kg of cement/per capita, a value higher than the amount of human food consumption [5]. The global average CO_2 emission per tonne of cement manufactures is estimated to be about 0.83 tonnes [6], meaning that the production of ordinary Portland cement accounts to 5% of world-wide CO_2 emission.

Why do we need to react?

The global population is expected to reach between 8.3 and 10.9 billion by 2050. Rapid population growth follows increased demand for clean water, air, land and need of housing and infrastructure. In a case where construction industry continues with "business as usual", taking into account the expected production increase, **in 2050 cement industry alone will contribute to 24% of total global CO_2 emission** [7]. Such high share of CO_2 emission for one industry alone will not be tolerated as the world acts to stabilise atmospheric pollution. To meet the people's need for urbanisation and at the same time satisfy European goals for protection of natural resources and lowering emissions, there is a strong motivation to develop more sustainable construction solutions with a lower environmental impact and in line with 7th basic requirement for construction works - sustainable use of natural resources [8].

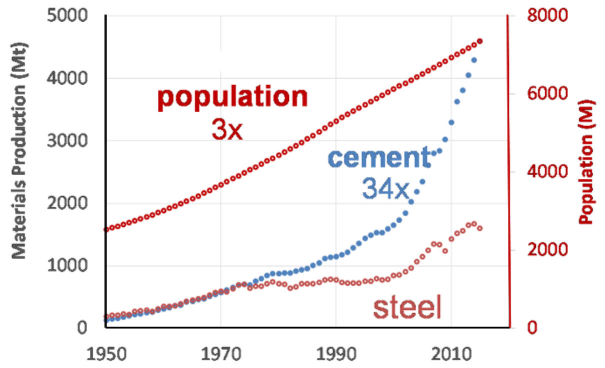

Figure 1 Increase in world population followed by exponential increase in cement production [28]

Which alternatives are there?

Considering that any improvement in cement, due to its dominant share in carbon footprint, can lead to a significant savings, the most scientific efforts are focussing towards developing **alternative binders for concrete (ABC)**. Alternative binders for concrete present a new generation of construction materials that are sustainable and economic alternative to ordinary Portland cement. Considering the vast societal challenge and huge amount of material in stake, it is obvious that there is no single solution to this problem and that all research knowledge must be mobilised. The list of potential ABC binders is continually growing, but some of the most potential candidates, that will be developed within the project are presented hereafter.

High volume supplementary cementitious materials (SCM)

Cement containing small amount of supplementary cementitious materials already make up the large majority of produced cementitious binders. The global clinker factor was estimated at 0.77, which means that on a total of 4200 Mt cement produced in 2015, at least 800 Mt of SCMs was used [9]. To create a more significant ecological effect, a push toward high-volume SCMs is inevitable [10], creating binders based on SCMs with small amount of cement used as an activator [11]. To meet a growing demand for cement and concrete and taking into account limited supplies of high-quality SCMs, research is focussed at alternative SCMs such as red mud [11], [12], copper slag, calcined clays [13], limestone [14], and their engineering combinations [15].

Alkali activated materials (AAM)

Alkali activated materials present any binder system derived by the reaction of an alkali metal source (activator) with a solid silicate powder (precursor) [16]. Solid can be a calcium silicate or aluminosilicate-rich, such as metallurgical slag, natural pozzolan, fly ash or bottom ash. The activators are soluble substance that supply alkali metal cations, raise pH of the mixture and accelerate the dissolution of the solid precursor. Most of the research is performed on fly ash and blast furnace slag as precursors [17], [18], but new solutions emerge, such as ferronickel slag [19], electric arc furnace slag, red mud [17] and calcined clay [20].

Calcium sulfoaluminate cement (CSA)

Calcium sulfoaluminate are based on two types of clinkers: sulfoaluminate belite clinker and ferrialuminate clinker [21], [22], in which different amounts of calcium sulfate are added [23]. Due to the low porosity of CSA cement concrete and ability of ettringite and AFm phases to bind heavy metals, they are of interest in the field of hazardous waste encapsulation. CSA cements are based on three raw materials - limestone, bauxite and calcium sulfate, and current research efforts are focussing on replacing some of these materials with industrial waste and by-products. Materials of special interest are fly ash [24], blast furnace slag, phosphogypsum, electric arc furnace slag, red mud and flue gas desulfurisation gypsum, etc.

Limestone calcined clay cement (LCC)

Limestone is used as a filler in cement industry; however, in recent years, it started to be used as a partial replacement for ordinary Portland cement [25]. One of the methods of activating reactivity of limestone is by adding reactive and silica-rich and alumina-rich materials, such as calcined clays [13], [26], [27]. In countries with established ceramic industry substantial reserves of suitable clays are currently stockpiled as waste [28]. Currently, research efforts are focussed on pinpointing types of clays, whose calcination would yield the most reactive material with acceptable ecologic footprint.

Hypothesis on which ABC project is built on are that:

1. there exist promising and beneficial raw materials for ABCs available in sufficient quantities as abundant waste or unused by-products in the proximate region,
2. using analytical methods and more fundamental approach, it is possible to unlock their potential and turn them from waste into valuable raw materials for developing ABCs
3. it is possible to correlate changes of ABC on microstructural level and implications on macrostructural properties, all for predicting their service life in aggressive environment.

The aim of the project is to establish research group as a centre of expertise for multiscale research of durability and microstructure of alternative construction materials, capable to autonomously use advanced analytical techniques provided by regional instrumentation network and trained by international centres of knowledge and excellence in the field.

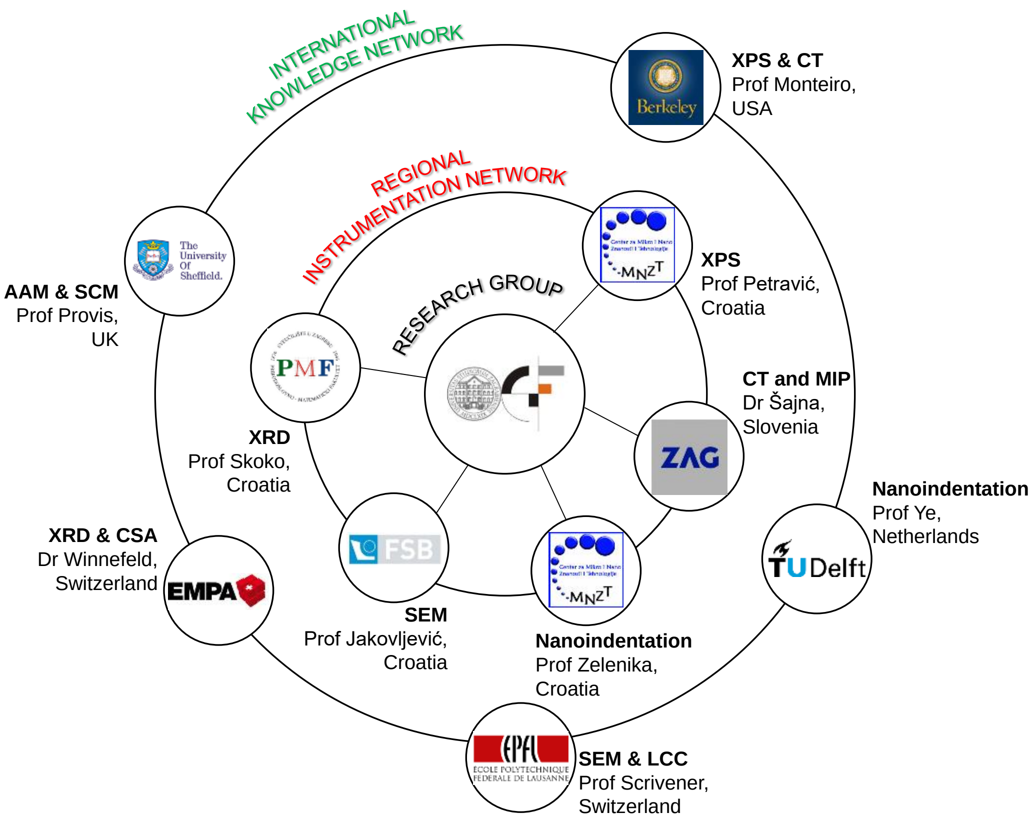

Figure 2 ABC research network