

# Concrete Repair With Geopolymeric Mortars. Influence of Mortars Composition on their workability and mechanical strength.

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**Abstract.** Since geopolymeric binders generates 70-80% less carbon dioxide than Portland cement this materials have been receiving increased attention, due to the need of reducing green house gas emissions generated by Portland cement and also to the need of new binders with enhanced durability performance. Several authors have report placement difficulties related to the low workability of geopolymeric mortars. Therefore, the purpose of this paper is to understand how their composition influences its workability and its mechanical strength.

This study has investigated the joint effect of several factors on the workability and mechanical strength of geopolymeric metakaolin based mortars. The factors analyzed through a laboratory experiment of 432 specimens, and of 48 different mortar mixes were, sodium hydroxide concentration (10M, 12M, 14M, 16M), the superplasticizer content (1%, 2%, 3%) and the percentage substitution of metakaolin by calcium hydroxide in the mixture (5%, 10%). The results show that the workability decreases with the concentration of sodium hydroxide and increases with the amount of calcium hydroxide and superplasticizer. The results also show that the use of 3% of superplasticizer, combined with a calcium hydroxide content of 10%, allows improving the mortar flow from less than 50% to over 90%, while maintaining a high compressive and flexural strength.

## Introduction

To make Portland cement clinker limestone is heated with a source of silica in a kiln at temperatures well over 1350 °C. The production of one tonne of cement generates 0.55 tonnes of chemical CO<sub>2</sub> and requires an additional 0.39 tonnes of CO<sub>2</sub> in fuel emissions for baking and grinding, accounting for a total of 0.94 tonnes of CO<sub>2</sub> [1]. Other authors [2] report that the Portland cement industry emitted in 2000, on average, 0.87 kg of CO<sub>2</sub> for every kg of cement produced. Current estimates of world cement manufacture are near 3000 Mt (millions tonnes)/year. Global demand will have increased almost 200 % by 2050 from 2010 levels. This is particularly serious in the current context of climate change caused by carbon dioxide emissions worldwide, causing a rise in sea level and the occurrence of natural disasters and being responsible for a future meltdown in the world economy [4, 5]. Furthermore, the search for more durable binders relates to the fact that reinforced Portland cement concrete structures deterioration is a very common phenomenon. Portland cement concrete presents a higher permeability that allows water and other aggressive elements to enter, leading to carbonation and chloride ion attack resulting in corrosion problems. This implies expensive conservation actions or building new structures.

Research works carried out so far in developing geopolymeric binders, show that this new material is likely to have enormous potential to become an alternative to Portland cement. Geopolymeric concrete have been receiving increased attention, due to the need of reducing green house gas emissions generated by Portland cement and to the need of new binders with enhanced durability performance [6].

Although research in this field has been published as “alkali-activated” binders, the term “geopolymer” is the generally accepted name for this technology. Geopolymerisation involves a chemical reaction between various aluminosilicate oxides with silicates under highly alkaline conditions, yielding polymeric Si – O – Al – O bonds indicating that any Si – Al materials could become sources of geopolymerisation. Geopolymeric binders generate 80% less carbon dioxide than Portland cement [7]. Weil et al. [8] mentioned that in comparison to Portland cement concrete the global warming potential (GWP) of geopolymeric concrete is 70% lower. The high cost of geopolymeric binders is one of the major factors which still remains a severe disadvantage over Portland cement [9-11]. Currently geopolymeric binders only become economic competitive for high performance structural purposes. In the short term the above cited disadvantage means that the study of geopolymeric applications should focus on high cost materials such as, commercial concrete repair mortars. Torgal et al. [12] show that geopolymeric mortars can be as much as 7 times cheaper than current commercial repair mortars. But if the cost to bond strength ratio were compared the differences are even higher, with the cost of the cheapest commercial repair mortar being 13,8 times higher than the geopolymeric mortars.

Geopolymeric mortars and concretes present a stiff workability behavior arising from the use of viscous compounds such as sodium silicate and sodium hydroxide. Several authors have reported placement difficulties related to the low workability of geopolymeric mortars. Some authors [13] show that several superplasticizers used in the Portland cement concrete industry lost their fluidifying properties for geopolymeric mortars. Other authors [14] found out that the use of a superplasticizer leads to an improvement of geopolymeric mortars workability but they can also contribute to a reduction on compressive strength depending on the sodium silicate to NaOH ratio. Sathonsaowaphak et al. [15] reported that workable ranges of sodium silicate/NaOH ratios and NaOH concentration are between 0.67–1.5 and 7.5–12.5 M. Also Rangan [16] confirmed that the addition of a naphthalene sulfonate-based superplasticizer improves the workability of fly ash geopolymer mixtures, however, a superplasticizer content above 2% is responsible for a slight degradation of compressive strength.

Therefore, the purpose of this paper is to understand how the composition of geopolymeric mortars influences its workability and its mechanical strength.

## Experimental work

**Materials. Geopolymer mortars.** The metakaolin used in this study was subjected to a thermal treatment at 650 °C during a few seconds using a flash calcination apparatus. The fine aggregate used was crushed sand from the same mine with a specific gravity of 3.0 a 24 hour water absorption of 1.0%, and a finess modulus of 2.8. The superplasticizer has been provided by MAISOL – FPR, with a density of  $1.100 \pm 0.005 \text{ g/cm}^3$ . A hydrated commercial lime powder supplied by Lusical with more than 70% of CaO and a density of  $0.46 \text{ g/cm}^3$  was also used.

## Mixture proportions and synthesis

The factors considered in this investigation led to the manufacture of 48 different mixes (432 specimens). The factors analysed were, sodium hydroxide concentration (10M, 12M, 14M and 16M), the superplasticizer content (1%, 2% and 3%) and the percentage substitution of metakaolin by calcium hydroxide in the mixture (5% and 10%). The mass ratio of sand/metakaolin/activator used was 2.2/1/1. Previous trials showed that a higher sand content leads to a very stiff behaviour and a lower one leads to liquid like mortar. The alkaline activator was prepared prior to use. An activator with sodium hydroxide and sodium silicate solution ( $\text{Na}_2\text{O}=13.5\%$ ,  $\text{SiO}_2=58.7\%$ , and  $\text{water}=45.2\%$ ) was used with a mass ratio of 1:2.5. Previous investigations showed that this ratio lead to the highest compressive strength results in alkali-activated mortars. Distilled water was used to dissolve the sodium hydroxide flakes to avoid the effect of unknown contaminants in the mixing water. The alkaline activator was prepared prior to use. Alkali-activated mortars were a mixture of aggregates, metakaolin, calcium hydroxide and alkaline silicate solution. The sand, metakaolin and calcium hydroxide were dry mixed before added to the activator. No extra water has been added.

## Test procedures

**Workability.** The workability assessment has been conducted with a truncated conical mould and a jolting table according to the EN 1015-3.

**Compressive strength testing.** Compressive and flexural strength data was obtained using  $160 \times 40 \times 40$  mm<sup>3</sup> cubic specimens according to EN 1015-11. The fresh mortar were cast and allowed to set at room temperature for 24h before being removed from the moulds and kept at room temperature (20° C) until tested in compression and flexural strength. Compressive strength for each mortar mixture was obtained from an average of 3 specimens from those broken in flexure.

## Results and discussion

Figure 1 presents the results of the alkali-activated mortars flow according to the sodium hydroxide concentration for several contents of superplasticizer and calcium hydroxide.

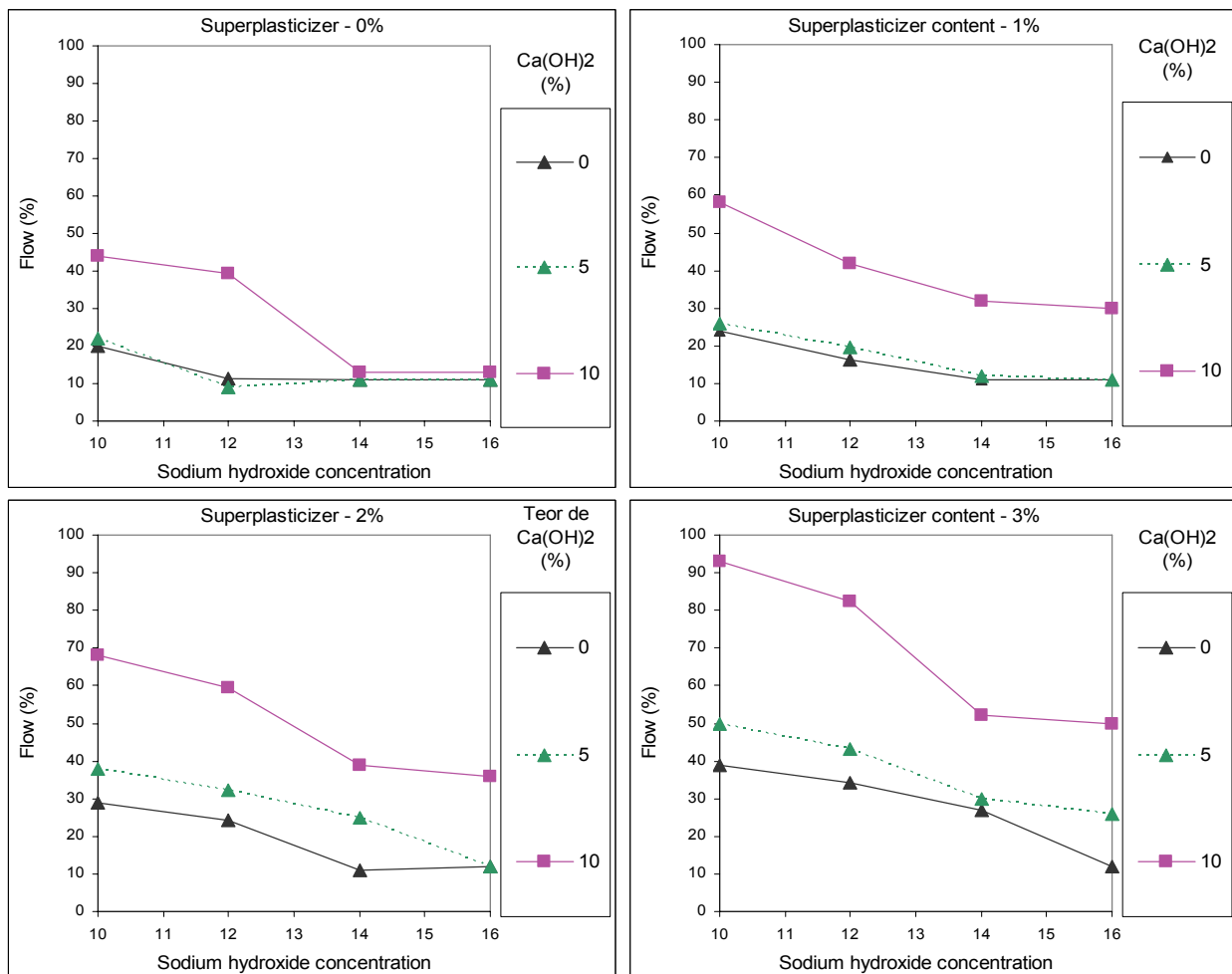


Fig. 1 – Flow versus sodium hydroxide concentration for several contents of superplasticizer and calcium hydroxide.

The results show that alkali-activated mortars without superplasticizer show a flow below 50%. Mortars with increase superplasticizer content show an increase flow. The mortars containing a high calcium hydroxide show a high flow because this mixture has a low percentage of metakaolin. Since metakaolin has a high Blaine fineness it needs a high liquid phase in order to be dissolved. Flow is also reduced with high sodium hydroxide concentration. The highest flow was achieved by mortars with a sodium hydroxide concentration of 10M and a calcium hydroxide of 10%. The use of a superplasticizer content of 3% combined with a calcium hydroxide content of 10%, allows increasing a mortar flow of less than 50% to over 90%. Similar findings were recently reported

[19]. Figures 2 show the compressive strength for 7 days curing versus flow in alkali-activated mortars according to the sodium hydroxide concentration and several contents of superplasticizer and calcium hydroxide.

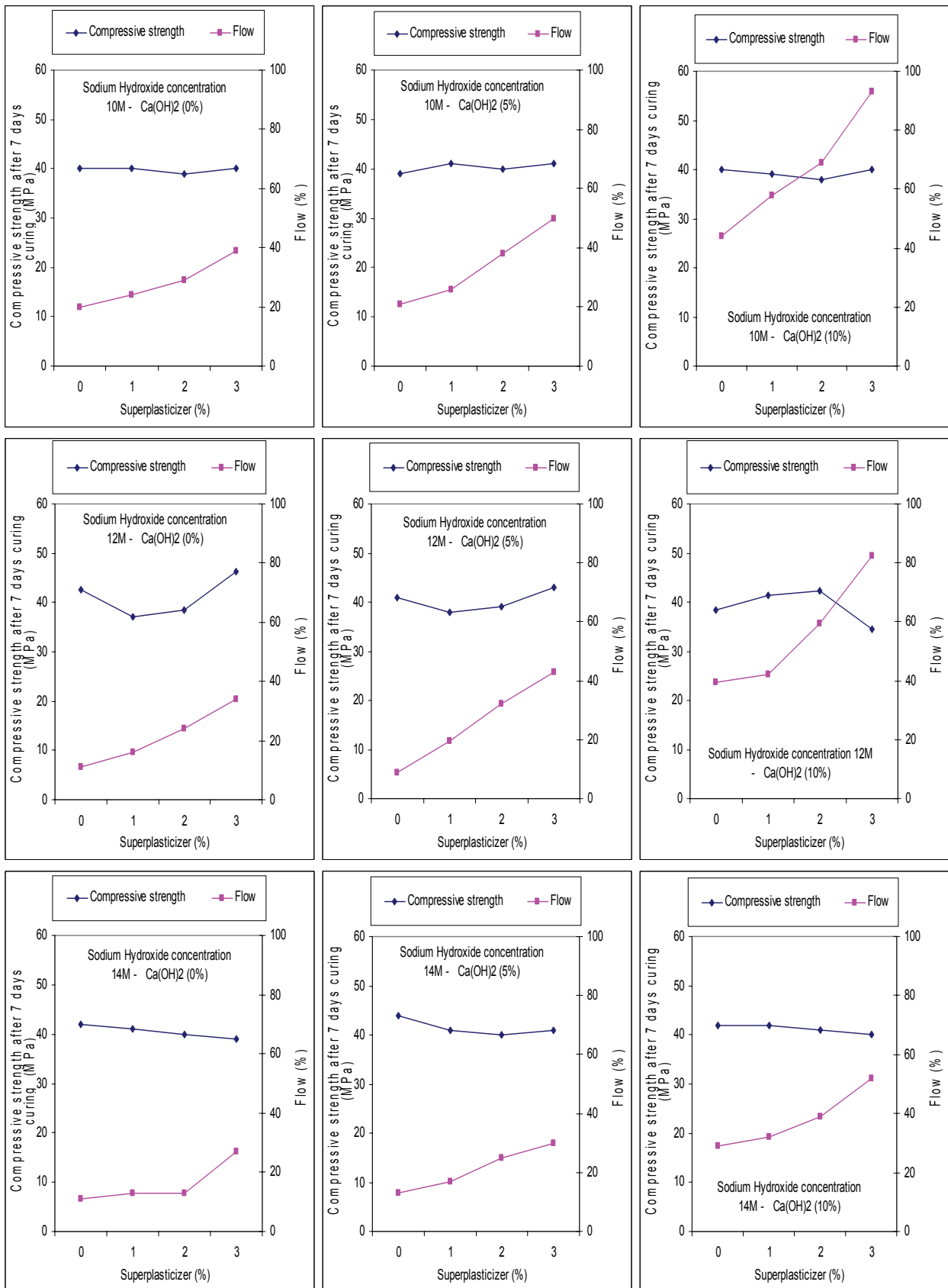


Fig. 2 – Compressive strength for 7 days curing versus flow in mortars with several contents of superplasticizer and calcium hydroxide: a) 10M, b) 12M, c) 14M,

In the mortars with a sodium hydroxide concentration of 10M, the flow increase due to the increase in the superplasticizer content is associated to an almost constant strength level, which is a different behavior from the one reported by other authors [13]. As for the mortars with a sodium hydroxide concentration of 12M and a 10% calcium hydroxide, when the superplasticizer content increase from 2% to 3% a flow increase is observed but at the same time a compressive reduction takes place. This confirms previous findings [14,15] and could be explained by high air entrained content. The compressive strength according to the curing days of geopolymeric mortars with 10% calcium hydroxide and 3% superplasticizer is showed on Fig. 3.

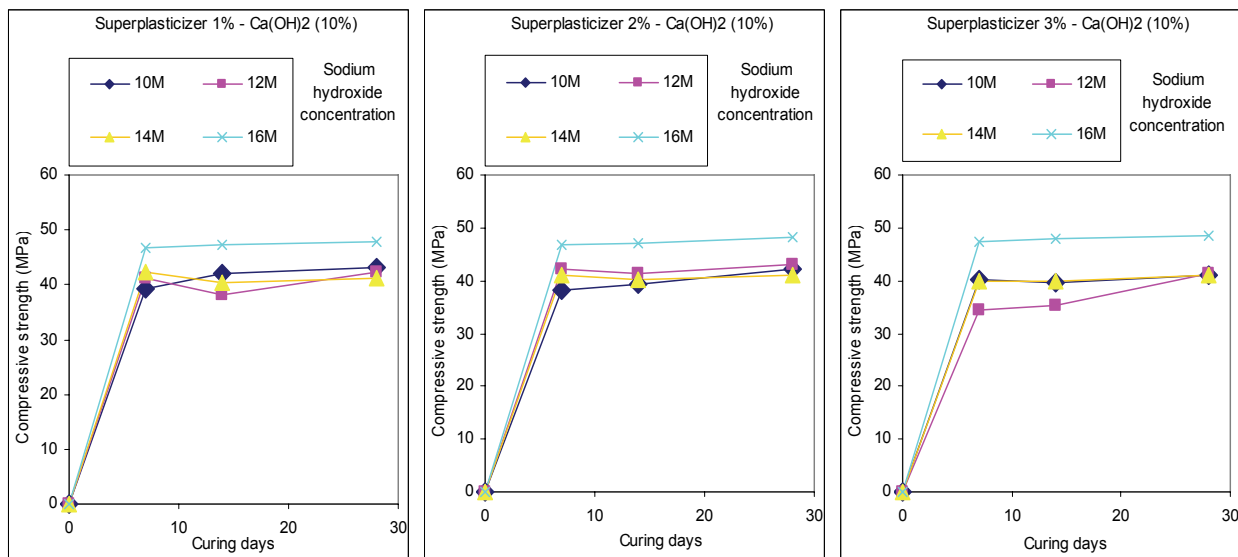


Fig. 3 – Compressive strength according to curing age for mortar mixtures with 10% of calcium hydroxide with several sodium hydroxide concentrations and different superplasticizer contents

The results show that higher sodium hydroxide concentrations lead to a compressive strength increase, but that only happens beyond 7 days curing. Higher concentrations of alkaline solution raises the pH which increases the dissolution and solubility of the aluminosilicate mineral waste and provides positive ions to balance the negative charge of the aluminate group [17,18]. The adverse effect reported by Lee et. al. [19] related to reduction in strength due to excess of alkali have not been confirm. With the exception of the mix with a sodium hydroxide concentration of 12M and a 3% of superplasticizer which needs 28 curing days to achieve a 40MPa compressive strength, the other can easily achieved a high mechanical strength just after 7 days curing. Some of them can even reach 50MPa.

## Conclusions

The results also show that the mortars workability is reduced with the increase of the sodium hydroxide concentration and also with a high replacement of metakaolin with calcium hydroxide, because metakaolin has a high Blaine fineness. The results also show that the compressive strength and flexural strength increased with and increased in sodium hydroxide concentration, in both cases that influence means an increase around 35%. The use of a superplasticizer content of 3% combined with a calcium hydroxide content of 10% is responsible for an increase in mortar flow from less than 50% to over 90% while maintaining a high level of mechanical strength. The results show that the use of a superplasticizer content up to 3% does not lead to mechanical strength reductions, with the exception of the mixture with a calcium hydroxide content of 10% and a sodium hydroxide concentration of 12M.

## References

- [1] E. Gartner, Industrially interesting approaches to low-CO<sub>2</sub> cements, *Cement and Concrete Research* 34 (2004) 1489-1498.
- [2] J. Damtoft, J. Lukasik, D. Herfort, D. Sorrentino, E. Gartner, Sustainable development and climate change initiatives, *Cement and Concrete Research* 38 (2008) 115-127.
- [3] M. Taylor, D. Gielen, Energy efficiency and CO<sub>2</sub> emissions from the global cement industry. International Energy Agency, Paris (2006)
- [4] IPCC, Intergovernmental Panel on Climate Change, 4th Assessment Rep. Assessment of observed changes and responses in natural and managed systems. *Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the 4th Assessment Report of the Intergovernmental Panel on Climate Change*, .In: Parry M. L., eds), Cambridge Univ. Press, pp. 79-131, 2007.
- [5] N. Stern, *Stern review on economics of climate change*, Cambridge University Press, 2006.
- [6] P. Duxson, J. Provis, G. Lukey, J. S.J. Van Deventer, The role of inorganic polymer technology in the development of green concrete, *Cement and Concrete Research* 37 (2007) 1590-1597.
- [7] P. Duxson, J. S.J. Van Deventer, Commercialization of geopolymers for construction – opportunities and obstacles. In *Geopolymers, Structure, Processing, Properties and Applications*, ISBN -13: 978 1 84569 449 4, Ed. J. Provis & J. Van Deventer, Woodhead Publishing Limited Abington Hall, Cambridge, UK: 2009, pp.379-400.
- [8] M. Weil, K. Dombrowski, A. Buchawald, Life-cycle analysis of geopolymers. In *Geopolymers, Structure, Processing, Properties and Applications*, ISBN -13: 978 1 84569 449 4, Ed. J. Provis & J. Van Deventer, Woodhead Publishing Limited Abington Hall, Cambridge, UK: 2009, pp.194-210.
- [9] J. Davidovits, Chemistry of geopolymeric systems. Terminology. In *Proceedings of 99 Geopolymere Conference* 1 (1999) 9-40.
- [10] J. S.J. Van Deventer, Opportunities and obstacles in the commercialisation of geopolymers. *Geopolymer 2002*. Melbourne.
- [11] R. Harper, W. South, R. Knigh, Geopolymers - a commercial reality? In *proceedings of 2002 Geopolymer Conference*. Melbourne, Australia.
- [12] F. Pacheco-Torgal, J.P. Gomes, S. Jalali, Adhesion characterization of tungsten mine waste geopolymeric binder. Influence of OPC concrete substrate treatment, *Construction and Building Materials* 22 (2008) pp.154-161.
- [13] M. Palácios, F. Puertas, Effect of superplasticizer and shrinkage-reducing admixtures on alkali-activated slag pastes and mortars, *Cement and Concrete Research* 35 (2005) 1358-1367.
- [14] P. Chindapasirt, T. Chareerat, V. Sirivivatnon, Workability of coarse high calcium fly ash geopolymer, *Cement and Concrete Composites* 29 (2007) 224-229.
- [15] A. Sathonsaowaphak, P. Chindapasirt, K. Pimraksa, Workability and strength of lignite bottom ash geopolymer mortar, *Journal of Hazardous Materials*, 168 (2009) 44-50.
- [16] B. Rangan, Engineering properties of geopolymer concrete. In *Geopolymers, Structure, Processing, Properties and Applications*, ISBN -13: 978 1 84569 449 4, Ed. J. Provis & J. Van Deventer, Woodhead Publishing Limited Abington Hall, Cambridge, UK, 2009, pp.211-226.
- [17] U. Rattanasak, P. Chindapasirt, Influence of NaOH solution on the synthesis of fly ash geopolymer, *Minerals Engineering* 22 (2009) 1073-1078.
- [18] P. Chindapasirt, C. Jaturapitakkul, W. Chalee, U. Rattanasak, Comparative study on the characteristics of fly ash and bottom ash geopolymers, *Waste Management* 29 (2009) 539-543.
- [19] W. Lee, J.S.J. Van Deventer, The effects of inorganic salt contamination on the strength and durability of geopolymers, *Colloids and Surfaces* 211 (2002)115-126.