Metakaolin as a climate-friendly cement substitute

Idea

The building industry has long been trying to move toward a more climate-neutral direction. This goal can be achieved by **reducing** the proportion of **cement clinker** in concrete, the production of which releases large **quantities of CO_2**.

The use of reactive additives can help with that. Slag and fly ash are frequently used for this purpose. These are industrial by-products that will no longer be available in sufficient quantities in the near future (closure of coal-fired power plants; relocation of the steel industry to other continents). These products delay the hardening of cement.

In contrast, kaolin and limestone are available in large quantities in the earth's crust. The substitution with limestone alone results in lower strengths. The reactivity of limestone powder depends on the limestone's origin and its fineness. These factors must be considered locally to obtain ideal results.

However, with **metakaolin** (burnt kaolin), this property can be regulated, and early strengths increased. Combining the technological advantages of metakaolin with the cost efficiency of stone dust can provide competitive and environmentally friendly alternatives to cement clinker.

Reaction mechanism of metakaolin

When combined with calcium hydroxide and water, pozzolans such as metakaolin, form water-insoluble CSH-phases (calcium-silicate-hydrate). These are the same phases that form during hardening (hydration) of cement. They increase the **strength and structural density** of concrete.

Compared to other pozzolanic admixtures, which are often characterized by slow setting, the high reactivity of metakaolin ensures rapid setting and fast-hardening concretes.

Test series

An extensive series of tests have been performed to show that the right mixture of cement with clinker substitution can achieve the same positive properties as cement alone.

Different cement mixtures with various concentrations of metakaolin (see Newchem's "new metakaolin types_2021") and limestone powder were used (see table). More than 30 mixes were tested for physical parameters (compressive strength, pozzolanic index, flexural strength, pH-value, mineralogical composition, etc.) after 2 and 28 days.

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Test results

- Cement with limestone powder

The increasing replacement of cement with limestone powder causes a significant decrease in the pozzolanic index (columns 1 to 3).

- Cement with metakaolin

With the partial replacement of the cement by metakaolin, the PI increased (compare column 1 - 3 to 4).

- Cement with metakaolin and limestone powder

When 26 wt.% cement is replaced with 8 wt.% metakaolin and 18 wt.% limestone powder (column 6), the PI corresponds to those of the respective cements after 28 days.

POZZOLANIC INDEX ACCORDING TO EN 13262												
Standard mortar		**1**		**2**		**3**		**4**		**5**		**6**	
		CEM II/A-LL (min)		CEM II/A-LL (max)		CEM II/B-LL		CEM II/A-Q		CEM II/A-M (Q-LL)		CEM II/B-M (Q-LL)	
CEM	wt.-%	90		83		74		90		83		74	
Water-binder value	wt.-%	0,5		0,5		0,5		0,5		0,5		0,5	
Metakaolin	**wt.-%**	-		-		-		**10**		**9**		**8**	
Limestone powder	wt.-%	10		17		26		-		8		18	
Sika FM6	wt.-%	-		-		-		0,67		0,44		0,44	
Cement type	**days**	**2d**	**28d**	**2d**	**28d**	**2d**	**28d**	**2d**	**28d**	**2d**	**28d**	**2d**	**28d**
Schwenk MV O	%	95,6	98,7	80,2	88,5	67,3	80,0	**102,0**	**124,0**	91,0	**124,0**	69,0	**109,0**
Schwenk MV K	%			72,0	90,2			88,0	**121,0**	72,0	**113,0**	60,0	**104,0**
Milke MV O	%	92,5	93,5	76,7	80,8	68,3	71,3	**110,0**	**120,0**	100,0	**119,0**	83,0	**106,0**
Milke MV K	%					71,7	71,5	**104,0**	**112,0**	93,0	**106,0**	76,0	91,0

Table: Comparison of the PI of different mixtures of cement, limestone powder and metakaolin.

The results of the tests are best demonstrated based on the pozzolanic index.

$$\text{Pozzolanic Index} = \frac{compressive\ strenght\ of\ the\ mixture\ with\ cement\ substitution\ x\ 100}{compressive\ strenght\ of\ the\ cement}$$

Conclusion

The tests showed that up to 26 wt.% of clinker can be replaced by metakaolin and limestone powder without reducing strength after 28 days.

Therefore, it is possible to create a cost-efficient and more climate-neutral alternative to pure Portland cement, while maintaining the same quality!

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