USING ADVANCED ADMIXTURES TO ENHANCE ACCELERATOR PERFORMANCE IN SPRAYED CONCRETE

DER EINSATZ EINES NEU ENTWICKELTEN ZUSATZSTOFFES ZUR VERBESSERUNG DER BESCHLEUNIGERWIRKUNG BEI HOCHLEISTUNGSSPRITZBETON

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Several flash setting alkali free accelerators are commonly available on the market and used for underground constructions. These admixtures cause a very rapid hardening of concrete thus allowing overhead and vertical applications. Their efficiency is very variable and dependent upon several parameters like: cement type and its chemical composition; environmental conditions (humidity; temperature); concrete mix design. Therefore, at job site, significant variations in terms of accelerator performances can occur. These effects can be extremely dangerous for worker safety as they can cause sudden collapses of the sprayed material. A new admixture was developed in our R&D Labs which can stabilize and enhance accelerator performance. This new powder based admixture is so effective in terms of mechanical strength development of the sprayed concrete layer that it can even allow a significant reduction in cement.

In this paper a review is presented of several job site tests where this new technology has been applied. The results clearly show exciting improvements in concrete technology. Underground projects are able to commence with many advantages hitherto unknown in traditional techniques. These improvements include lower cost, higher safety, lower rebound, greater speed and even environmental improvements due to the reduction in CO_2 emissions (lower cement = lower carbon footprint).

Zur Zeit sind verschiedene alkalifreie Spritzbetonbeschleuniger mit sehr schnellen Erstarrungszeiten auf dem Markt. Diese Erstarrungsbeschleuniger bewirken eine sehr schnelle Erhärtung des Betons und erlauben so einen Auftrag in größeren Schichtdicken an vertikalen Flächen und auch über Kopf. Die Wirksamkeit dieser Erstarrungsbeschleuniger ist sehr unterschiedlich und hängt von vielen Parametern ab, wie z.B.: dem Zement Typ und seiner chemische Zusammensetzung, den Umgebungsbedingungen (Feuchte, Temperatur), der Betonmischung (W/Z, Gesteinskörnungen...). Dadurch kann es auf der Baustelle zu unterschiedlicher Wirksamkeit der Erstarrungsbeschleuniger kommen. Diese Einflüsse auf die Wirksamkeit können unter extremen Bedingungen sehr gefährlich für die Mineure werden, da es bei schlechter Wirksamkeit zu Ablösungen des Spritzbetons über kopf kommen kann. Deshalb haben wir in unseren Forschungs- und Entwicklungsabteilungen einen neuen Zusatzstoff entwickelt, der die Wirksamkeit des Beschleunigers erhöhen und stabilisieren kann. Dieser neue pulverförmige Zusatzstoff ist so wirksam auf die Frühfestigkeitsentwicklung des Spritzbetons, dass man den Zementgehalt in der Betongrundrezeptur reduzieren kann.

In dem folgenden Beitrag wollen wir die Wirksamkeit dieser neuen Technologie anhand von Labor- und Baustellenversuchen darlegen. Die Ergebisse zeigen klar eine Verbesserung der derzeitigen Spritzbetontechnologie. Diese neue Technologie hat viele Vorteile gegenüber der herkömmlichen Technologie: niedrigere Kosten, mehr Sicherheit, weniger CO_2 Emmision aufgrund des geringeren Zementgehaltes.

1. Introduction

Alkali-free accelerators are relatively new liquid concrete admixtures used in the field of underground constructions [1,2,3,4,5]. For safety reasons they are replacing the classical alkali-rich accelerators, like sodium aluminate or sodium silicate in the European market. Furthermore, the concrete sprayed with these new alkali-free accelerators can reach higher long term compressive strength [6]. The accelerating admixtures cause concrete to set fast, thereby allowing cementitious material to adhere to the tunnel wall. This shotcrete lining acts as a consolidating shield useful to control tunnel convergence [7].

Several alkali-free accelerators are available on the market. They can be divided into two main categories both containing aluminium sulphate complexes stabilized either by inorganic or by organic acids [8]: (e.g. formic acid, uric acid).

The capability of concrete to stick onto the substrate is related to the efficiency of the reaction between accelerator and hydrating cement. This reaction is commonly evaluated by measuring the final set time or the compressive strength development of accelerated cement pastes [9, 10]. It can be influenced by several parameters such as: accelerator type and its solid content, type and chemical composition of cement, setting regulator, environmental conditions, concrete temperature and aggregates. The number of variables can be extremely dangerous for worker safety as inconsistencies can cause sudden collapses of the sprayed material. Furthermore, to increase sprayed concrete mechanical performance, an increase in accelerator and cement content is often necessary, thus increasing infrastructure costs and risks of cracks in the applied layer.

Moreover, cement is a raw material with high environmental impact. For example, the construction of a short tunnel (7 m of diameter and 1 km of length) coated with 0.3 m of sprayed concrete, requires at least 1630 ton of cement. The production of this cement results in the emission of about 1076 tons of CO_2.

A new admixture has been developed which can stabilize and enhance accelerator performance. Moreover, this new mineral powder based admixture (Accelerator Aid Agent) is so effective in terms of mechanical strength development and final strength of the sprayed concrete layer that it can allow a significant cement reduction in the applied layer.

In this paper the effects of this new admixture, called **Accelerator Aid Agent (AAA)**, on the mechanical strength development of several mortars and concretes are presented.

2. Experimental

Two cement pastes were prepared by mixing a Portland cement (cement type CEM I 42,5 R) with water (w/c ratio 0.35) and the addition of a polycarboxylate superplasticizer. The second sample also contained **AAA** (12.5 % of binder). The amount of plasticizer was chosen in order to give the same fluidity to both samples.

Having obtained an homogeneous slurry, a commercial alkali-free aluminium sulphate based accelerator (Al/S molar ratio: 1.03) was added and its content was adjusted to obtain a final setting (according to Vicat's method; EN 196/3) of the cementitious slurries lower than 2 minutes. The final setting values are reported in Table 1.

Table 1: Setting time of cement paste with CEM I 42,5 R

Components	**Mixture 1 (g)**	**Mixture 2 (g)**
Cement	100	87.5
AAA	0	12.5
Superplasticizer	0.70	0.87
Water	35	30.6
Accelerator Dosage (% of cement mass)	8	6
Final set	4 min	3 min 10 sec
Accelerator Dosage (% of cement mass)	9	7
Final set	1 min 40 sec	1 min 50 sec

The compressive strength development of cement mixtures containing our commercial alkali-free accelerator with and without AAA was measured. The tests were carried out on mortar samples having the compositions reported in Table 2. The mortars were prepared according to EN 196/1. **AAA** was added to cement, whereas the alkali free flash setting accelerator was added at the end of the mixing cycle and further mixed for 10 sec. At early curing ages, the mechanical strength in N was measured with a digital force gauge (Guideline Sprayed Concrete, Österreichische Vereinigung für Beton- und Bautechnik, Wien, 2009). At later curing ages the mechanical strength of the specimen (40x40x160 mm) was measured according to the EN 196/1. The results are summarized in Table 3.

Table 2: Mixture design for the determination of mechanical strength of mortar

Components	**Mixture 3 (kg/m³)**	**Mixture 4 (kg/m³)**
Cement IV/A-P 42.5 N	480	431
AAA	0	54
Superplasticizer	2	7
Accelerator	29	26
Aggregate (0-2.5 mm)	1449	1454
Water	217	194

Table 3: Compressive strength development

Mixture	**Penetration Stress (N) and mechanical strength (MPa)**						
	0.5 h	1 h	2 h	4 h	6 h	8 h	24 h
3	12 N	37 N	54 N	67 N	75 N	100 N	11.0 MPa
4	155 N	0.5 MPa	1.2 MPa	3.3 MPa	4.1 MPa	5.3 MPa	10.8 MPa

Four concretes were prepared and the influence of AAA to early age strength development was evaluated. These concretes were sprayed (Meyco Potenza, Putzmeister PM 500) with a commercial alkali-free accelerator and **AAA**. The compositions are reported in Table 4. Concrete samples were mixed according to EN 480/1. At early ages, the mechanical strength was measured with a Proctor Penotrometer and from 2 N/mm² with the Hilti powder-actuated tool according to the OEVBB Guideline Sprayed Concrete and according to EN 14887 and EN 14888-2.

In Figure 1 the slump of the concrete mixtures 6 and 6a are shown. As can be seen, there are no significant differences observable. As example, the application of the concrete mixture 6a is shown in Figure 2.

Figure 1: Slump of mixture 6 (left) and 6a (right)

Figure 2: Spraying of mixture 6a

The results of the early strength development measurements of the different sprayed concrete mixtures are reported in Figs 3-6.

Table 4: Concrete mix design

Components	**Mix 5**	**Mix 5a**	**Mix 6**	**Mix 6a**	**Mix 7**	**Mix 7a**	**Mix 8**	**Mix 8a**
	kg/m³							
Cem II/A-S 42.5 R (Rohrdorfer)	420	380	/	/	/	/	/	/
Cem I 52.5 R (Deuna)	/	/	380	340	/	/	/	/
Cem I 52.5 R (Heidelberger)	/	/	/	/	380	340	/	/
Cem II/B-M 52.5 N (Holcim)	/	/	/	/	/	/	400	360
AAA	/	**20**	/	**20**	/	**20**	/	**20**
Acrylic based Superplasticizer	2.9	3.4	3.4	3.8	3	3.7	4	4.3
Aggregate (silicate) (0-8 mm)			X	X	X	X	X	X
Aggregate (carbonate) (0-8 mm)	X	X						
Alkailfree Accelerator	25.2	22.8	19	17	20.9	18.7	28.0	25.2
Water	191	175	192	170	189	173	199	182
Water/Cement ratio	0.46	0.46	0.50	0.49	0.50	0.51	0.50	0.50

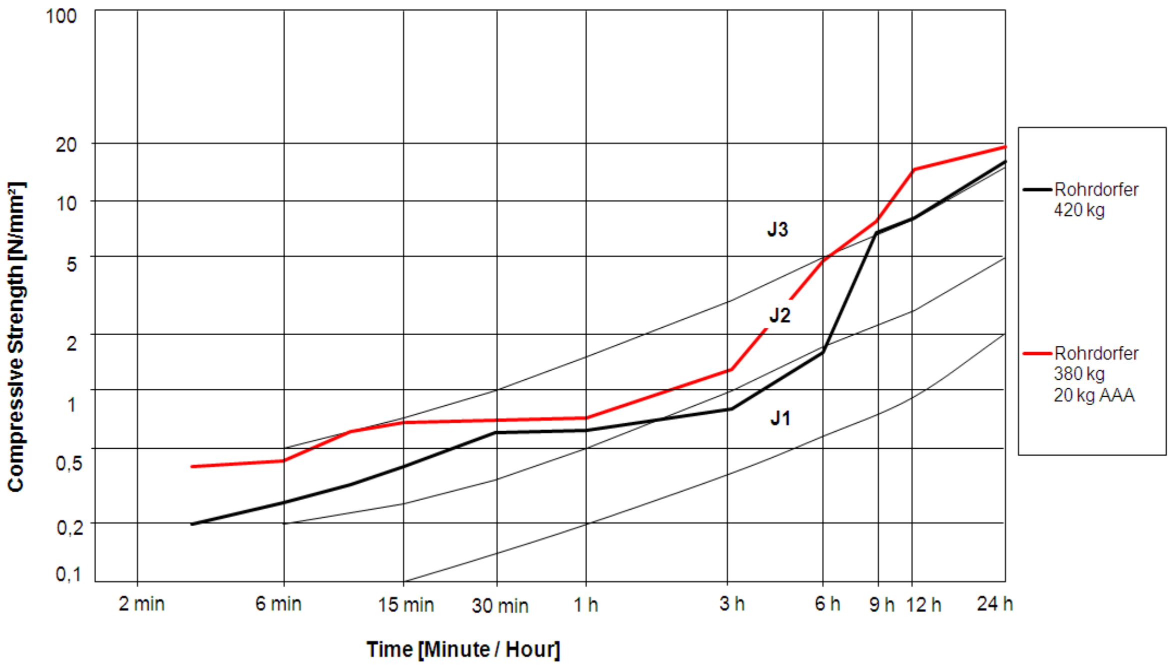

Figure 3: Early strength development of Mixtures 5 and 5a

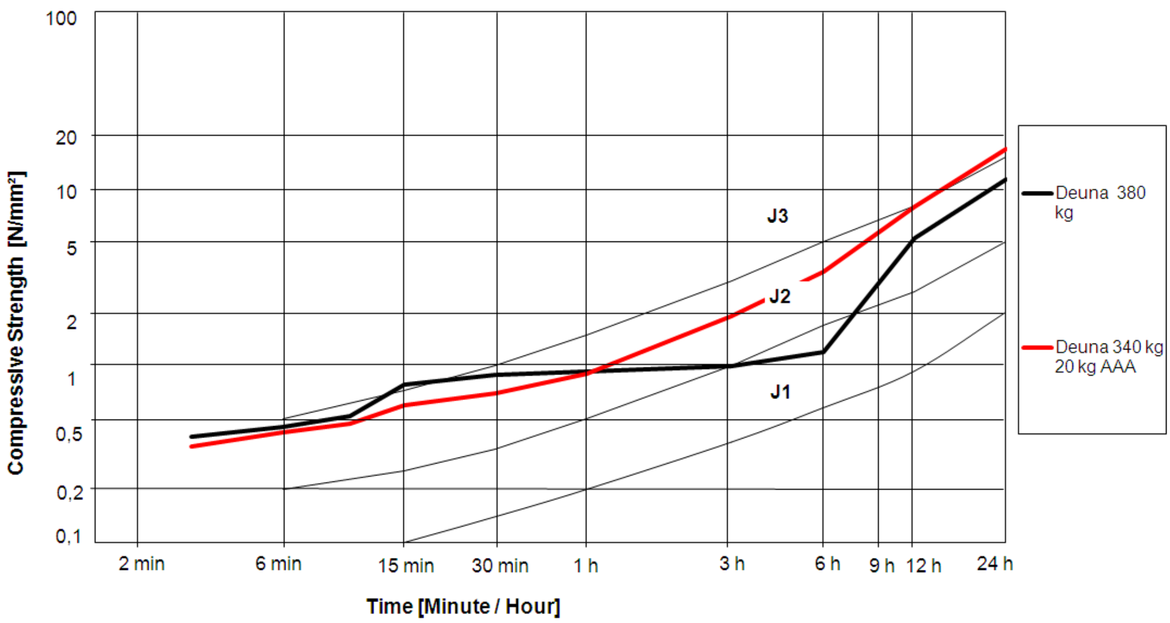

Figure 4: Early strength development of Mixtures 6 and 6a

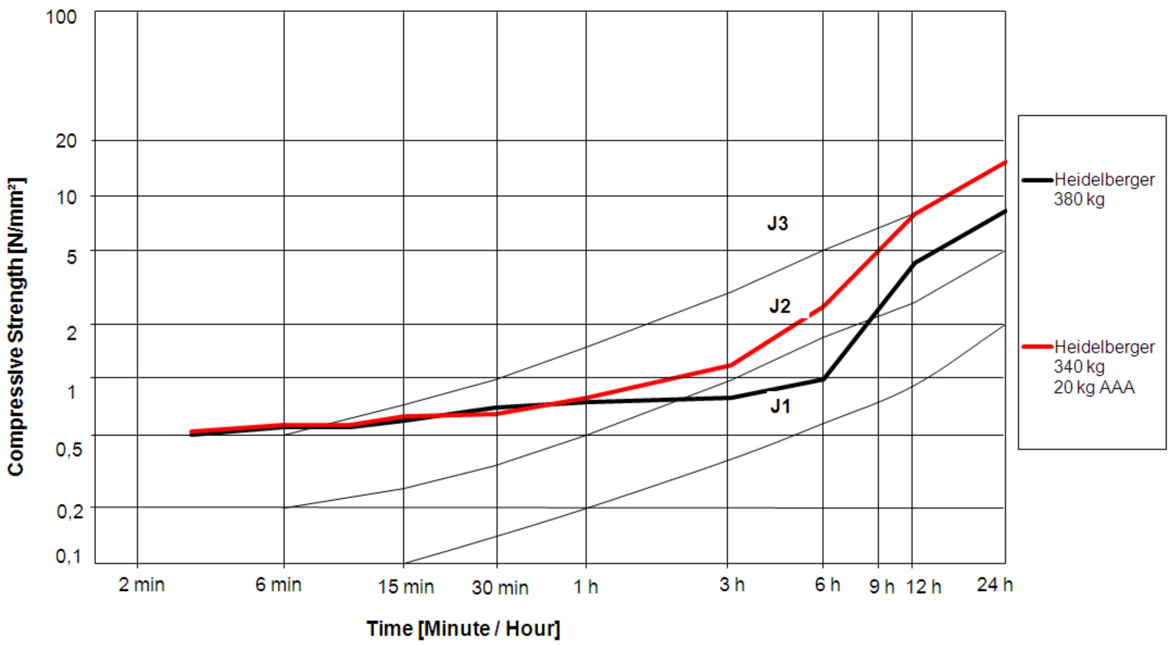

Figure 5: Early strength development of Mixtures 7 and 7a

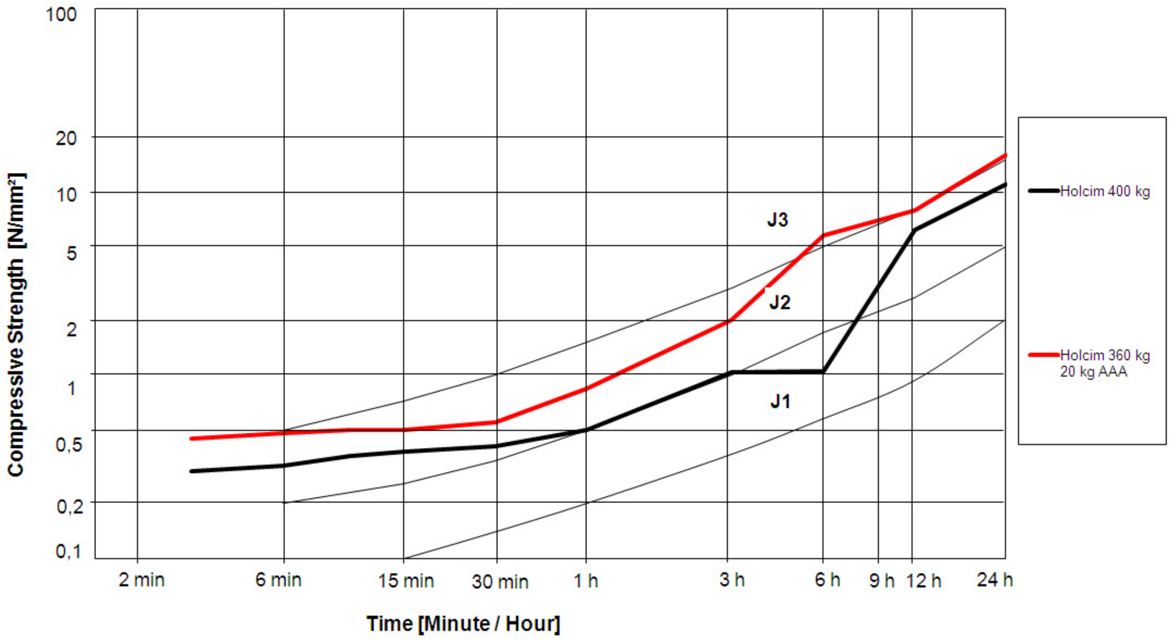

Figure 6: Early strength development of Mixtures 8 and 8a

3. Results and discussion

The results shown in Table 1 (pure cement pastes) point out that Mixture 2, containing **AAA**, is characterised by a final setting time of lower than 2 minutes with an accelerator dosage of 7 % (of cement mass) instead of 9 % for Mixture 1 without **AAA**. Mixture 2 reaches the same setting time although its cement and accelerator content is lower.

The results of Table 3 (mortars) emphasize that Mixture 4 (containing **AAA** and a lower cement content and lower alkali free accelerator) develops much higher early age strength than Mixture 3 without **AAA**.

Also job site tests with sprayed concretes confirm this trend (Figs 3-6): Mixtures 5a, 6a, 7a and 8a admixed with **AAA** and containing lower cement content and lower dosage of alkali-free accelerator show higher or at least similar early age strength development compared to the reference samples without the new admixture.

Workability tests also pointed out that **AAA** does not significantly affect concrete workability up to 90 minutes.

4. Conclusion

The results reported in this paper clearly indicate that this new technology for sprayed concretes or mortars with alkali free accelerator allows:

- a significant reduction in cement content
- a significant reduction in liquid flash setting accelerator dosage without affecting the early age strength development.

The reduced consumption of cement and alkali free accelerator leads to:

- lower construction costs
- lower environmental impact.
- Improved dimensional stability of sprayed concrete leading to improved durability.

Accelerator performance is more constant and less dependent upon external parameters, thus:

- tunnelling activities can speed up
- worker´s safety can be enhanced.

AAA is also suitable for flash setting alkali free accelerators with low aluminium sulphate concentrations.

The efficiency of this new technology was demonstrated but further studies are necessary in order to investigate chemical interactions of cement, accelerator and **AAA**.

5. References

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