Spritzbetonzusatzmittel auf Kalziumaluminatbasis

SHOTCRETE ADMIXTURE BASED ON CALCIUM-ALUMINATE MINERALS

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Die Neue Österreichische Tunnelbauweise kommt in Japan beim Bau von Eisenbahn- und Straßentunneln und bei der Errichtung unterirdischer Kavernen für Kraftwerke und Treibstofflager zur Anwendung. Vor allem die Zusatzmittel entscheiden über Qualität und Verbundverhalten des Spritzbetons. Das vorgestellte Zusatzmittel basiert auf mineralischen Kalziumaluminaten, ist pulverförmig und wird für die Beschleunigung von Zement verwendet. Dieses Produkt ist weitverbreitet und hält in Japan einen Marktanteil von 80 %. Das Zusatzmittel erhärtet mit Wasser und zeigt mit wachsender Zugabe bessere Erhärtungseffekte. Deshalb kann das Produkt bei Wasserandrang erfolgreich eingesetzt werden. Zur Zeit kommt das Zusatzmittel beim Naßspritzverfahren zum Einsatz, das sich für Tunnel mit großem Durchmesser besonders gut eignet. Das Referat beschreibt die Eigenschaften des Zusatzmittels, die physikalischen Eigenschaften des Mörtels und des Betons bei Verwendung dieses Zusatzmittels und geht schließlich auf Anwendungen im Tunnelbau ein.

In Japan NATM was introduced and applied railway and road tunneling works and excavating works of power plants and fuel depot under the ground. Especially shotcrete admixture plays the important role on deciding quality and bonding of shotcrete concrete. The shotcrete admixture which is based on calcium-aluminate minerals by melting is a powder type admixture and an application of quick-setting of cement. This admixture is used widely, 80 % share of shotcrete admixture in Japan. Because this admixture is hardened itself with water, the mixture quantity increase, the better hardening effect becomes. Therefore effective work can be done where water is springing. Currently this admixture is used for wet method which is appropriate for large cross-section tunnels. This report describes the properties of this admixture, the physical properties of mortar and concrete with this admixture and the applications for tunneling.

1. Introduction

In recent years, with the increased use of the New Austrian Tunneling Method (NATM) in railway and highway tunnel work, and underground cavern excavation work such as for underground powerhouse and fuel storage facilities, development of new technologies for this construction method and reviews of conventional construction methods have been actively carried out. With the 1986 revision of the Japan Society of Civil Engineers Standard Specifications, NATM has come to be treated as a standard construction method for mountain tunnels. Accordingly, the importance of shotcrete has been recognized anew, and besides quick-setting properties of shotcrete naturally, reductions in loss of materials due to rebound and in occurrence of dusting are being demanded. Further, with increases in cross-sectional sizes of tunnels, technological development has been going on for improvement in shotcrete application capacities, and results are beginning to be obtained.

Shotcrete admixtures presently being used in Japan may be broadly divided into inorganic salt-type and cement-type (highly basic calcium-aluminate mineral type). Inorganic salt-type shotcrete admixtures have alkali aluminates as their main components and are based on accelerating reaction of C_3A in cement. Cement-type shotcrete admixtures, along with accelerating reaction of C_3A in cement, increase quick-setting power by the self-hardening properties of the shotcrete admixtures themselves.

Shotcreting systems may be broadly divided into dry-mix and wet-mix processes, and as a recent trend, wet-mix systems are adopted more for large cross-section tunnels of two-lane highway tunnel class for reasons such as that

1. Larger volumes can be placed with a wet-mix process,
2. Quality control of concrete is easier with a wet-mix process, and
3. There is less occurence of rebound loss and dusting with a wet-mix process.

As a result of using a shotcrete admixture based on calcium-aluminate minerals (hereafter referred to as "this SA") in a wet-mix system, excellent performance was obtained compared with other inorganic salt-type shotcrete admixtures, and along with describing this SA, the physical properties when added to mortar and concrete and examples of application are reported in this paper.

2. Present states of shotcrete admixtures

Shotcrete admixtures now being marketed in Japan may be broadly divided into the five categories below, and the principal components, physical properties, dosages in reaction to cement, quick-setting properties, and otherwise, features in application methods are given together in **Table 1** and as follows.

This SA (Type A): prominent quick-setting power; placement in thick coats and use at water-springing locations possible

Type B: dosage small for low cost, but alkalinity strong

Type C: improved type with weaker alkalinity

Type D: no clogging of pipeline and suitable when using wet sand in large amounts

Type E: low alkalinity and suitable for wet-mix process requiring stable, high strength.

Type B, C, and D are shotcrete admixtures termed as inorganic salt-types with alkali aluminates and alkali carbonates as main components. These admixtures accelerate reaction of the C_3A in cement, and there are powdered forms (B, C) and a liquid form (D).

This SA is a new type which uses as its raw material a cement mineral obtained by melting of calcium-aluminate. This SA has a self-hardening property so that quick-setting power is strong in proportion of dosage, and reduction in long-term strength is small compared with no addition of shotcrete admixture. Consequently, it is possible for pneumatic application to be made in thick coats and at water-springing locations.

Type E is a shotcrete admixture of special type and consists of calcium sulfoaluminate mineral. The hydration products consist mostly of ettringite ($3CaO \cdot CaSO_4 \cdot 3Al_{188}O_3 \cdot 32H_2O$), the alkalinity is weak, and there is extremely little chemical harm done to the human body. The setting power is strong and compressive strength of 50 kgf/cm² or more can be obtained. Although the dosage is high at 10 to more than 20 percent, it can be added in slurry form, and a new use far quick-setting concrete is being developed.

Item \ Type	Type A This SA	Type B	Type C	Type D	Type E
Component	Calcium-aluminate mineral	Inorganic salt	Modified inorganic salt	Inorganic salt liquid	Calcium solfo-aluminate
Specific gavity	2.7	2.5	2.5	1.5	2.9
Fineness [cm²/g]	4200	1000 - 2400	1000 - 4200	-	5400
Standard dosage (% vs cement)	5	3	5	5	10

Table 1: Classification of shotcrete admixtures

3. Physical properties of mortar using this SA

A shotcrete admixture greatly influences the quality and workablity of concrete. The Japan Society of Civil Engineers has specified setting measured by Proctor penetration resistance as the quality test for quick-setting properties of shotcrete admixtures. This is a test method in which ordinary portland cement is used to prepare mortar of C/S = 1/3 at W/C = 0,5, adding shotcrete admixture to make quick-setting mortar and measuring its time of setting by Proctor penetration resistance. Incidentally, the Japan Society of Civil Engineers standard stipulates that initial set (500 psi) is to be within 5 minutes and final set (4000 psi) within 15 minutes.

The results of Proctor penetration tests of mortars with additions of shotcrete admixtures Types A to E are shown in **Figure 1**. The test mix proportions and the materials used were:

Cement: ordinary portland cement

Sand: Hime River natural river sand (specific gravity ρ = 2.63, F. M. = 2.90)
C/S = 1/3,
W/C = 0.50,
testing temperature = 20 °C.

The test results may be summarized as follows:

This SA (Type A): Quick-setting power becomes stronger in proportion to the quantity added.

Tye B: Quick-setting property is exhibited with a small dosage of 3 to 4 percent, but there is no proportionate relationship between dosage and quick-setting property.

Type C: Quick-setting property is weaker compared with Type B. A dosage of about 7 percent is the maximum and when more than this is added, quick-setting property is conversely weaked.

Type D: This is a liquid type with a peak at a dosage of about 7 percent, and the properties are similar to those of Type C.

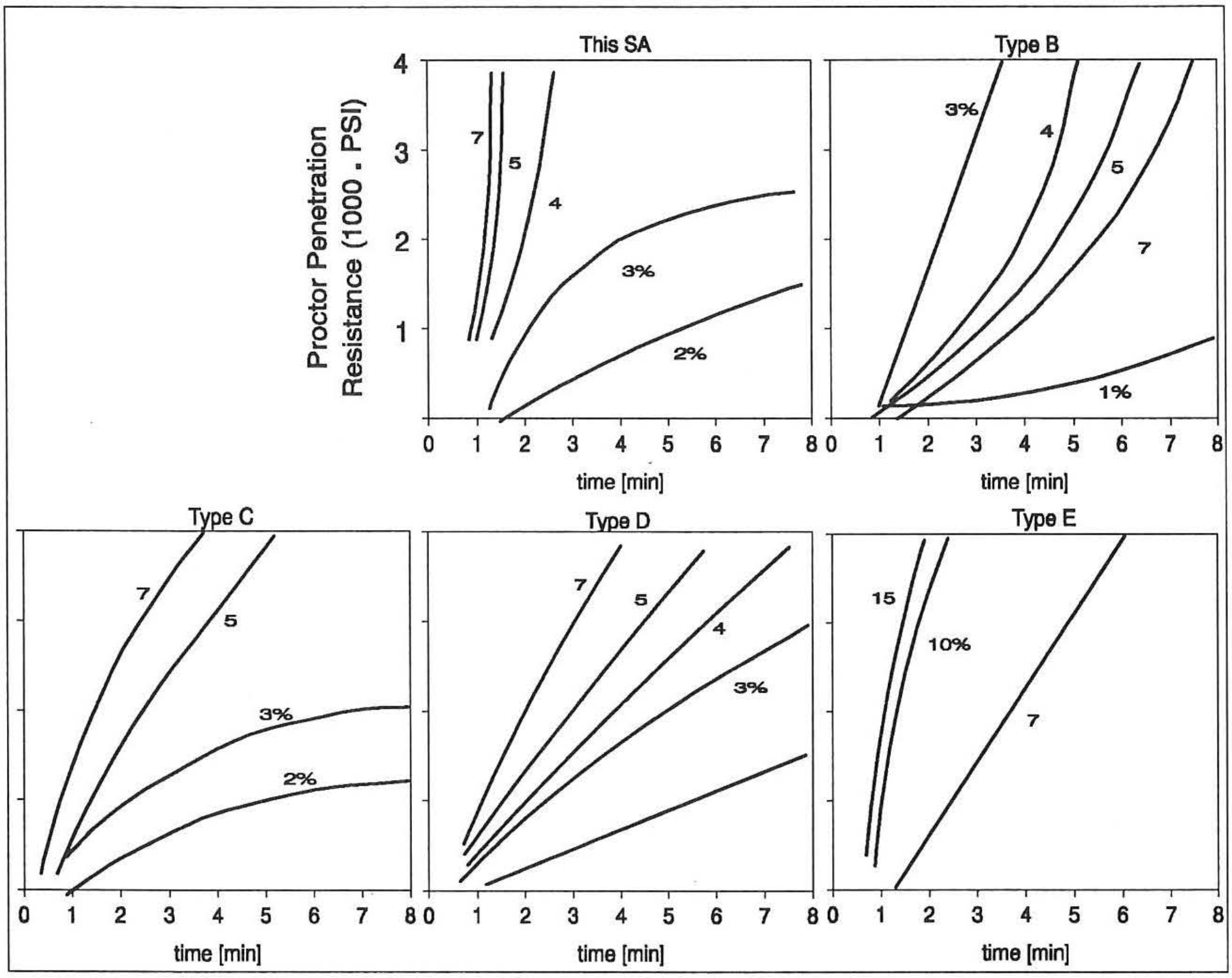

Fig. 1: Quick-setting properties by type of shotcrete admixture

Type E: Quick-setting property becomes stronger in proportion to dosage, and prominent strength gain is attained simultaneously with quick-setting. However, a dosage of more than 10 percent is necessary.

Next, the results of compressive tests on mortars with additions of Types A, B, and E, and mortar with no addition are given in **Table 2.** The test mix proportions and materials used were the same as for the Proctor penetration tests. The testing temperature was 20 °C, with the curing conditions sealed at 20 °C for 1 day and curing in water subsequently at 20 °C.

Type B is overtaken by the mortar with no addition in 3 to 7 days, and the gain in strength is small. In comparison, the mortar with this SA has long-term strength approximately equal to that of mortar with no addition, and there is practically no reduction in strength even though shotcrete admixture is added. Type E produces a hydrate of ettringite, accelerates hydration of cement, and long-term strength is higher than for no addition. With the use of shotcrete admixture of Type E, it is possible to produce even thick primary linings.

In order to confirm the self-hardening property of this SA, raw materials making up the various shotcrete admixtures were added individually to cement and heat of hydration amounts were measured by calorimeter. Of the results, those of hydration within 1 hour are shown in **Figure 2** and those up to 24 hours in **Figure 3.** As raw materials comprising shotcrete admixtures, calcium-aluminate mineral and sodium carbonate, sodium aluminate were used.

From the fact that heat evolution in case of addition of 5 percent calcium-aluminate mineral is great it can be seen that heat of hydration of the shotcrete admixture raw material itself was additinal to the heat of hydration of cement and strength gain is greater than for raw materials of other inorganic salt-type.

Type	This SA		Type B		Type E		No add. of SA	
Age	Strength [kgf/cm²]	Ratio [%]	Strength [kgf/cm²]	Ratio [%]	Strength [kgf/cm²]	Ratio [%]	Strength [kgf/cm²]	Ratio [%]
3 hrs.	17.0	680	9.0	360	22.0	880	2.5	100
1 day	124	133	132	142	140	150	93	100
3 days	185	114	170	105	243	150	162	100
7 days	274	108	193	76	308	122	252	100
28 days	313	107	206	71	343	117	292	100
6 months	320	106	215	71	378	126	301	100
1 year	325	107	220	72	390	128	305	100

Table 2: Compressive strength on mortar with shotcrete admixtures

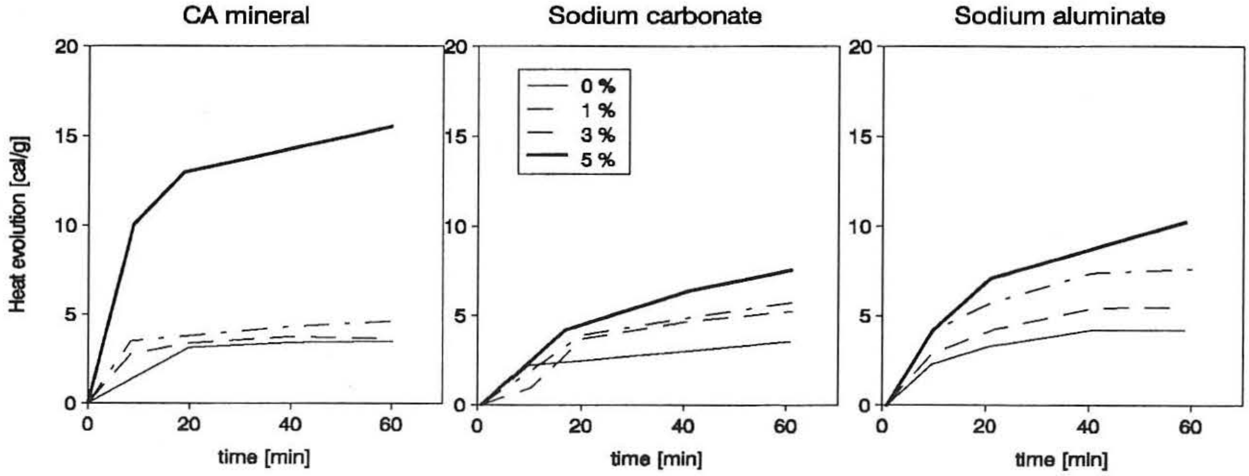

Fig. 2: Heat of hydration within 1 hour

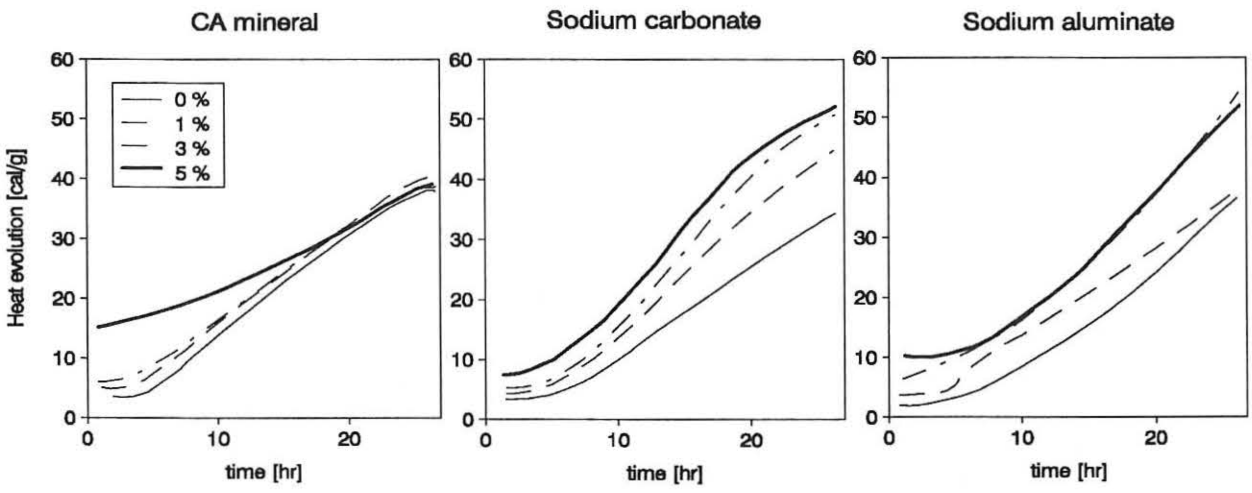

Fig. 3: Heat of hydration within 24 hours

4. This SA in wet-mix process and physical properties of shotcrete

As previously mentioned, shotcreting methods can be broadly divided into dry-mix and wet-mix processes. Until several years ago, dry-mix processes were more often adopted in tunneling work. As advantages of dry-mix process, whereas the following may be cited.

1. Mechanical apparatus is of small size (for ease of addition of shotcrete admixture).
2. Operation is easy.
3. The distance of pressurized conveying of shotcrete may be made longer.

But on the other hand, there were shortcomings such as

1. The quality of concrete (adjustment of water-cement ratio) is governed by the skill of the nozzleman.
2. Dust and rebound are of comparatively large quantity.
3. Placing capacity is small.

As the use of the NATM spread, there was an increase in large cross-section tunnel projects and wet-mix processes have come to be mostly used for reasons such as

1. Placement in larger volumes is possible with wet-mix processes.
2. Quality control of concrete is easier.
3. Less dust and rebound occur compared with dry-mix processes.

Table 3 shows the transitions in methods used in NATM tunnel projects in 1987 and 1988. The data are the results of surveys made by authors' company and do not cover all tunnels, but it is considered that the trend can be recognized.

Year	1987		1988	
Method	Number	Ratio [%]	Number	Ratio [%]
Wet-mix processes	98	56	146	77
Dry-mix processes	78	44	44	23

Table 3: Transitions in method used in NATM tunnel projects

Whereas in 1987 wet-mix and dry-mix process projects were roughly equal in number, in 1988, wet-mix processes made up three fourths and dry-mix processes one fourth, showing an increase in wet-mix processes. The transitions in NATM tunnel procets according to owners are shown in **Table 4**.

Year	1987		1988	
Method	Number	Ratio [%]	Number	Ratio [%]
Japan Highway Public Corp.	63	38	97	33
The Ministry of Constr.	20	12	81	27
A local self-govern. body	39	23	55	19
Japan Railways	25	15	6	2
Electric power companies	14	8	23	8
The others	6	4	32	11

Table 4: Transitions in NATM tunnel projects according to owners

Compared with relatively small cross-section railway tunnel and power generation headrace tunnel projects there has been a marked increase in highway tunnel projects, and this is thought to have led to the increase in wet-mix processes.

The tunneling work by wet-mix processes has increased greatly in Japan due to development of this SA and development of delivery apparatus for powdered shotcrete admixture for wet-mix processes besides the beforementioned features. In addition of liquid shotcrete admixtures, pumptype apparatus are used, and controlling the dosage is easy for a high level of constant feed. However, in case of wet-mix shotcreting with powdered shotcrete acmixtures, systems of forcibly delivering the shotcrete admixture into hose by pneumatic pressure were adopted, but there were problems about constant quantity and continuity. Therefore, in order to eliminate these problems, a powdered shotcrete admixture delivery apparatus was developed. This apparatus consists of a section for delivery from a pressure tank and an air dryer for removing drains from compressed air containing moisture for delivery by compressed air of high pressure.

The amount of delivery of shotcrete admixture is adjusted by the number of revolutions of a rotary disk at the bottom of the pressure tank. Therefore, the rotary disk was set in vertical form so that its rotation would not fluctuate according to the weight of the shotcrete admixture in the tank, thus improving the constant feed property. The specifications of apparatus are given in **Table 5.**

Item		Contents
Capacity of the tank	[l]	150
Pressure	[kgf/cm²]	2-5
The amount of delivery	[kg/min]	1-5
The number of revolution	[rpm]	1,2-7,7
Electric motor	[KW]	0,2
Weight	[kg]	650

Table 5: The specifications of apparatus

Next, shotcrete by the wet-mix process with addition of this SA will be described. It is stated in the Standard Specification for Tunnels that "the strength of shotcrete is generally based on 28-day compressive strength, but in case of shotcrete development the early strength is of importance from the standpoint of design." Furthermore, the Standard Specification for Concrete clearly state that initial strength is "strength within 24 hours of application."

That is, in actual construction, considerable weight is placed on initial strength and for control of initial strength, the Japan Society of Civil Engineers "Quality Standard for Shotcrete Admixtures (Draft), JSCE-1986" are adopted as table tests, but since conditions differ from actual shotcrete, there is a necessity nevertheless for control to be exercised with actual shotcrete samples from the jobsite. As the method of testing initial strength of shotcrete, the Japan Society of Engineers Standard Specifications prescribe

1. Initial Strength Tests of Shotcrete by the Pull-out Method
2. Initial Strength Tests of Shotcrete using Beams.

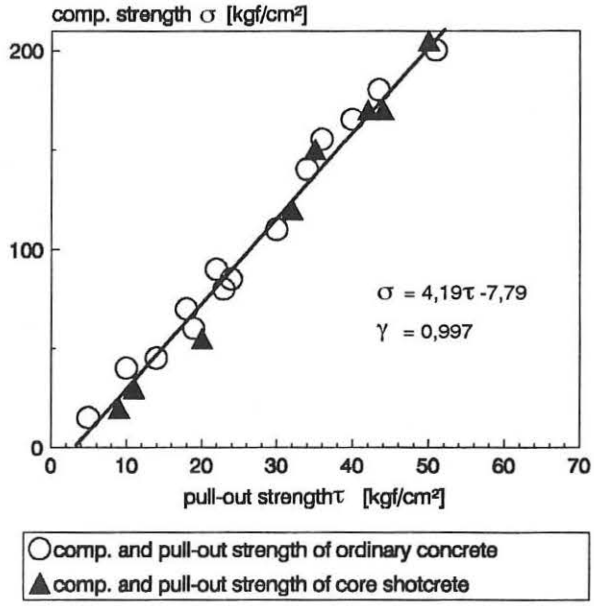

Fig. 4: Compressive strength and pull-out strength of concrete

In (1), however, compressive strength is not directly determined, but is estimated from shear strength and when the calibration coefficient is sought there is a correlation as shown in **Figure 4.**

The Japan Highway Public Corporation controls initial compressive strength of shotcrete on basis of

$$\sigma \approx 4\tau \qquad (1)$$

where, σ = compressive strength
τ = shear strength.

The results of compressive strength tests of shotcrete using this SA, and shotcrete admixtures of Type B and D are shown in **Figure 5.**

The mix proportions of the shotcretes were as given in **Table 6**, these being standard-type mix proportions for the wet-mix process. Application was done using a sprayer of rotary type from among air delivery system. Compressive strength were obtained up to 3-day age through calculations by the abovementioned Eq. (1) based on the results of pull-out tests.

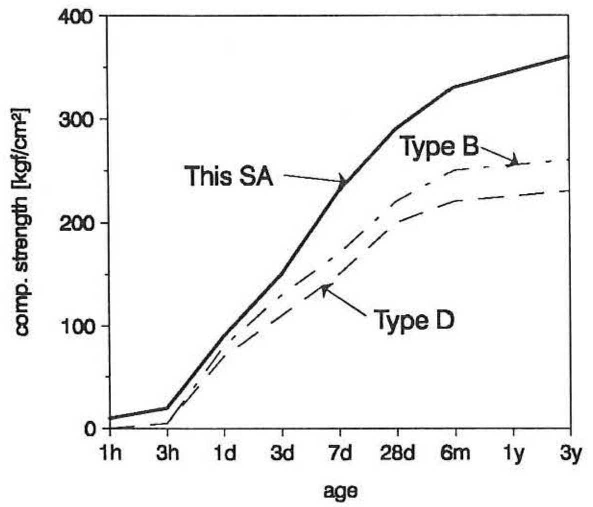

Fig. 5: The results of compressive strength test of shotcrete

G_{max}	[mm]		13
W/C	[%]		60
S/a	[%]		60
Slump	[cm]		8 ± 2
Weight	[kg/m³]	Water	216
		Cement	360
		Fine agg.	1026
		Coarse agg.	689

Table 6: The mix proportions of shotcretes (wet-mix process)

Shotcrete using this SA has rapid strength gain up to the age of 1 hour, and even at portions of thick application, the increase in bond strength of the shotcrete is greater than its dead weight, so that it is possible for application to be done in thick coats. By the same token, this strength gain makes possible application at water-springing locations. Furthermore, there is less reduction in compressive strength at long-term age than shotcretes using shotcrete admixtures of B and D types, and it may be said that this SA is a shotcrete admixture which is stable even at long-term ages.

Data according to type of shotcrete admixture used in NATM tunnel projects in 1987 and 1988 are shown in **table 7**. In NATM tunnel projects in Japan the features of the previously mentioned calcium-aluminate shotcrete admixture have won high regard so that it is being used at practically all tunnel jobsites. This has been or is being used in primary lining shotcrete of highway tunnel projects of the north-south and lateral expressways of the Japan Highway Public Corporation making up the truck highway network of Japan, railway tunnel projects of Japanese Railways Supplementary Shinkansen lines, underground powerhouse and headrace tunnel projects of hydroelectric power stations, and construction projects of the three fuel strage bases of Kuji, Kikuma, and Kushikino of Japan Underground Oil Storage.

Year	1987		1988	
Shotcrete admixture	Number	Ratio [%]	Number	Ratio [%]
This SA	122	92	201	84
The other CA-SA	0	0	9	4
Inorganic salt-type	11	8	28	12

Table 7: Data according to type of shotcrete admixture

5. Conclusions

The matters that can be concluded based on properties of this SA and features with the use of this SA in wet-mix processes are as follows:

1. This SA has a self-hardening property itself so that quick-setting power becomes strong in proportion to dosage.
2. This SA has a self-hardening property itself so that reduction in long-term strength is small compared with no addition of shotcrete admixture.
3. Development of delivery apparatus for powdered shotcrete admixture with controlling constant feed has increased the tunneling works by wet-mix processes.

4. Shotcrete used this SA has rapid strength gain for self-hardening property itself, so that it is possible for application to be done in thick coats and at water-springing locations. Furthermore, there is less reduction in compressive strength at long-term age, and it may be said that this SA is a good admixture which is stable even at long-term ages.

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