

EXPANSIVE CEMENTS AND SOUNDLESS CHEMICAL DEMOLITION AGENTS: STATE-OF-TECHNOLOGY REVIEW

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ABSTRACT

Expansive cements and soundless chemical demolition agents (SCDAs) were first introduced in the early 1970s but failed to gain widespread adoption for selective removal of rock and concrete due to their proprietary nature and a lack of usage guidelines. Nearly 40 years later, the patents have expired, and a large number of competitive products have entered the market. These factors coupled with a heightened interest in their potential environmental benefits have greatly expanded their usage. Specifically, these chemicals can be introduced into a pattern of small, drilled holes in concrete and/or rock. After a specific period (usually less than 24 hours), the in-situ material will crack sufficiently that it can be removed without the use of traditional explosives or further percussive efforts. The products generate substantially less noise and vibration than usually associated with the removal of rock and concrete. This paper provides a state-of-the-technology review of five available products. The focus is on the proposed applicability of various products under specific conditions. Special attention is paid to the viability of such agents under varying temperatures and with materials of particular strengths.

1. INTRODUCTION

Demolition of concrete and rock is a common process for many construction, renovation and rehabilitation projects. Among well-known methods, the most common are explosives, which generate the lowest cost (Table 1) [1], and the mechanical crushing and

breaking [2]. However, these methods require a large staging space on the site and/or generate a large amount of vibration, flyrock, gas and dust. Many are also skittish about their use due to potential lawsuits from nearby residents [3].

Table 1. Comparison of SCDA with others

Kinds	Breaking Power	Situations at the work site				Safety	Simplification of Protection*	Economy*
		Noise	Ground Vibration	Dust Gas	Flyrock			
Explosives (Dynamite)	◆	X	X	X	X	X	X	◆
Explosives (Concrete Cracker)	O	Δ	Δ	X	Δ	Δ	X	O
Rock Breaker	Δ	Δ	O	O	◆	O	◆	Δ
Hydraulic Splitter	O	◆	◆	◆	◆	◆	◆	X
SCDA	O	◆	◆	◆	◆	◆	◆	O

◆ Superior (or pollution-free); O: Good; Δ: Marginally inferior; X: inferior (or with pollution); * Results differ subject to circumstances

To avoid such negative aspects, several potential demolition methods are often marketed including controlled blasting, hydrodemolition [4]; thermal concrete demolition [5] and diamond blade sawing or diamond wire cutting method [6]. Unfortunately, they only tend to reduce and not eliminate problems with flying debris, safety, smoke, and fire hazards. As a result, these methods are judged unacceptable for demolition in inhabited and environmentally sensitive areas. Soundless Chemical Demolition Agents (SCDAs) that are also known as expansive cements have been proved as a potential alternative demolition method with clear advantages over the others methods as discussed below.

2. SCDAs

2.1 Background

SCDAs are powdery materials (Table 2) that expand considerably when mixed with water through chemical hydration, by the formation and development of ettringite crystals [1][7]. Under confinement, this expansion can generate significant expansive pressure, which causes cracking of rock or concrete, when it exceeds the tensile capacity of materials. To apply the material, holes are drilled into the rock/concrete, and the SCDA is poured into the holes. Then pressure builds and overcomes the confining pressure of the surrounding material, which will break the rock or concrete, without flyrock, noise, ground vibration, gas, dust, or other environmental pollution when used properly.

Table 2. Chemical compositions of SCDAs

Substance	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃
Composition (%)	1.5-8.0	0.3-5.0	0.2-3.0	81-96	0.0-1.6	0.6-4.0

Although SCDAs were first marketed in 1970 [8], arguably they originated from the expansive cement first identified from the investigation of ettringite in cement in the 1890s by Candlot and Michaelis [9]. The intentional production of an expansive cement can be dated back to Henri Lossier in France in the mid-1930's. Over the next 20 years, Lossier concluded that an ideal expansive cement was composed of Portland Cement, an expansive

component, and blast-furnace slag [9]. Lafuma (1952) later discovered that ettringite could develop during the hydration of a mixture of Portland cement and anhydrite or gypsum with including an expansive component [10]. After that, there were further studies in the 1980s, but most were concerned with the chemistry of the expansive cements, with only minimal attention paid to the physical response [11]-[16]. In the late part of the last century, application of SCDAs were investigated by researchers in the laboratory, as well as field [17]-[24], but the products were not extensively adopted in the market, in part because of a lack of published guidelines and a limited availability of manufacturers. This paper attempts to begin to overcome the knowledge deficit by introducing a state of technology review for SCDAs.

2.2 State of technology review

A commonality amongst SCDAs is in their general application approach, which involves the following steps:

1. Clear and prepare work site
2. Design and layout hole pattern subject to demolition needs
3. Drill the holes to the design depth and diameter
4. Promptly pour the mixed demolition agent into drilled holes
5. The chemical reaction occurs
6. The rock/concrete is then cracked and diminished in size suitable for mechanical removal

Since the performance of SCDAs concerns splitting materials, in practice, there are arguably three parameters that need to be controlled related to the cracking mechanism: (1) time to first crack in the sample, (2) cumulative crack width at 24hours, and (3) minimum demolition time (MDT), which is the time to reach 25.4mm of crack width, or another pre-specified crack width which allows a sample is to be easily removed from its surrounding material. In terms of those aspects, it is possible to identify these effects: ambient temperature and temperature of mixed water to be used; material properties of the samples, and the construction practice effects.

2.2.1 Effects of temperature

SCDAs are known by several names (e.g. soundless cracking agent, expansive cracking agent, and expansive cement) as a form of non-explosive breaking technology. In general, SCDAs were designed to be used in wide range of ambient temperature from -8°C to 40°C , although some can work at temperatures of up to 50°C (Table 3). As such, manufacturers classify their own product lines into different types based on suitability with specific temperature ranges. Recent work by Laefer et al. [24] showed that in general, the higher the ambient temperature, the faster the cracking occurs and that products designed for colder temperatures can be used in warmer environments to speed up the cracking. Overall, time to first crack ranges from a few hours to nearly a day, and crack widths of 10-30mm can be obtained within a day depending upon dimensional and material properties (Table 3). Additionally, some products seem intentionally marketed to minimize the time to first crack (Table 3) reporting as little a half the time of other products. According to Laefer et al. [24], in standalone concrete blocks of 1m^3 , time to first crack ranged 13-19.67hrs, with an average of 15.48hrs at 22.1°C (Fig. 1). They also concluded that MDT was achieved in just over 24hrs [24].

In 1994, Hinze and Brown [21] concluded that surrounding temperature was a more dominant factor on expansive pressure than boreholes size or water content. Their work also concluded that expansive pressure increased approximately twice when increasing the ambient temperature from $20-30^{\circ}\text{C}$, and there could be a further 50% increasing of pressure, if ambient temperature was increased 50% to 45°C . Prior work conducted by Dowding et al. [17] pointed out that when decreasing ambient temperature 10°C , expansive pressure decreased 30% at 24hrs and 10% at 48hrs.

Beyond ambient temperature, effects of water temperature on expansion have also been studied to a limited extent. Normally, mixed water temperature was proposed not to exceed 15°C and the ratio of water and SCA powder should be 1:3 by weight (28-34%) [Table 3].

Hinze and Brown's work [21] showed that expansive pressures decreased 25%, when water content increased 4%. Hinze and Nelson [22]

showed that when water content was reduced to by 2.3% to 27.7%, expansive pressure increased 19.8% over that achieved with the recommended 30% water content. Furthermore, in the latest study in concrete, Laefer et al. [24] reduced time to first crack 18.92%, when the mix water was heated to 37.8°C (an increase of 152% over the 15°C recommended by the manufacturer). In addition, cumulative crack width at 24hrs was also larger, and MDT was 11.54% less than that attained at 15°C .

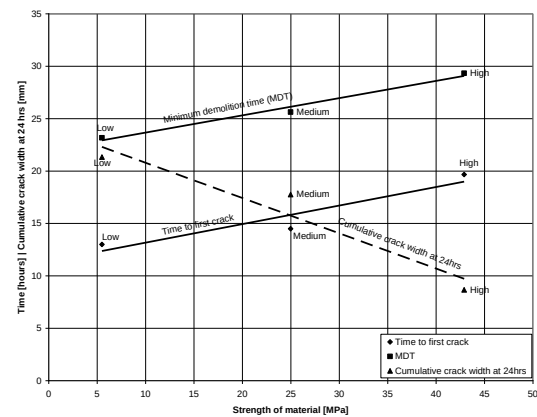


Fig. 1. Crack patterns versus strength of material

2.2.2 Material properties effects

In SCA usage the depth, size, orientation, and distance of drilled holes have all been shown to affect crack size and development time. They not only controlled cracking of rock or concrete but also impact demolition costs, if the users can optimize SCA usage by improved understanding of these parameters. Hole diameters ranged 30-65mm depending on material to be cracked, with distances between holes generally 20-70cm, and as much as 100cm apart (Table 3). These spacings ensure that crack migration between holes connect. Gambatese [23] proposed further cost reductions by interposing uninjected holes amongst those injected with SCDAs [23] (Fig. 2), but this increases noise, vibration, and drilling costs and has not been adopted in industry.

Depth of holes were generally recommended between 80-90% the depth of the sample to be broken, although 70% has been shown to be consistently effective, at least for some products [1][24]. For the 80-90% depth

Table 3. Specifications of some popular various SCDA's products

Product	Performance expectations	Usage instructions			Application specifics		
1. Prostar	- Time required for crack formation in material at 20°C is about 3-6hrs - Crack width reaches 10-30mm after several days. - Type1: 25-40°C Type2: 10-25°C Type3: -5-10°C	Materials	Water/scda	Kg/m³	D (mm)	L (cm)	Depth
		Soft rock	30% (<34%) Water temp: 15°C	5-8	36-50	50-70	80% H
		Medium rock		8-12		30-60	80% H
		Hard rock		12-20		40-60	80% H
		Plain conc.		5-8		40-70	90% H
		RC less bars		10-25		30-40	90% H
		RC much bars		20-35		25-35*	90% H
		Anti-fire brick		10-25		N/A	90% H
		Ambient temp. (°C)		Water temp. (°C)		Depth: Boulder 80%H; Bench:105%H * L for RC much bars should be 20-30cm when steel content >100kg/m³	
		-5~10		40			
		10-30		20-25			
		>30		<15			
2. CrackAG	- Crack appear in 6-8hrs (max. 48hrs expanding time) -Type1:20-35°C;Type2:10-25° Type3: 5-15°C;Type4: -8~5°C - Filling SCDA 15mm from the top of holes	Materials	Water/scda	Kg/m³	D (mm)	L (cm)	Depth
		Soft stone	1:3	8-10	35-50	40-60	H+5%H
		Hard stone	Water temp: 15°C (<25°C)	10-15	35-65	40-60	H+5%H
		Rock cutting		5-10	30-40	20-40	H
		Plain concrete		8-15	35-50	40-60	80%H
		RC		15-25	35-50	15-30	90%H
3. Chemshine	- Crack appears 10-20hrs, reaches 10-30mm after several days. Super: crack at 40’ -3hrs. -B100:15-35°C;B150:10-20° B200:5-15°C;B300:-5~5°C - Super2000: H:25-35; M:15-30; L:5-15°C	Materials	Water/scda	Kg/m³	D (mm)	L (cm)	Depth
		Soft stone	30% (<34%)	5 RC: larger than 2-4 times	40-50	60-100	Any
		Hard stone	B100,150:15°			50-100	
		Presplitting.	B200: 10°C			30-60	
		RC: found., pillar, beam	B300: 5°C			25-50	
		RC: wall, slab	H:25,M:20,L: 15°C			20-30	
4. Buster	N/A Temperature: 5-50°C	Materials	Water/scda	Kg/m³	D (mm)	L (cm) (Dx10)	Depth
		All	28-30% 10-12°C (<15°C)	8	30-65	30-65	80-85%H
5. Dexpan	- Cracks appear after 2hrs (max. expanding time: 48hrs) -I: 25-40,II:10-25,III:-5~10°C	Materials	Water/scda	Kg/m³	D (mm)	L (cm)	Depth
		All	1:3 (temp: N/A)	N/A	38-51	<=31 RC: <=25	80-90%H

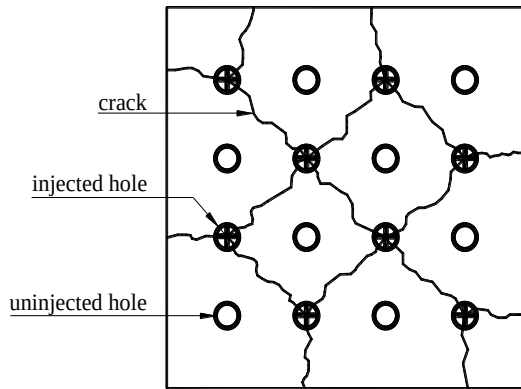


Fig. 2. Holes on sample surface

coring, the quantity of SCDA to demolish 1m^3 of soft rock/concrete ranges from 5-8kg, 10-15kg for hard rock, and 15-25kg for reinforced concrete. Furthermore, higher strength material requires more time to generate the first crack in the sample and crack width of 25.4mm, as well as less cumulative crack width at 24hrs [1],[24].

In a study to identify the optimum distance between holes, Gomez and Mura [20] proposed $L=Dk$ for determination of hole spacing for various material strengths, where L is the distance between holes, D is the diameter, and k is an in-situ material property, with $k < 10$ for hard rock; $8 < k < 12$ for medium rock; $12 < k < 18$ for soft rock and concrete; and $5 < k < 10$ for reinforced concrete. Gambatese's work in concrete [23] concluded dissimilar results, $4 < k < 10$, thereby halving the allowable distance between holes proposed by Gomez and Mura [20]. This disjunct may have been an outgrowth of Gambatese's extremely small-scale samples (152.4 x 152.4 x 76.2mm specimens with hole diameters as small as 3.18mm), which were cast without material scaling. In a latter study, in concrete with boreholes of 31.8mm and $k=12$, Laefer et al. [24] consistently achieved a crack width of 25.4mm within 24hrs, if the strength of material was less than 12MPa.

2.2.3 Construction practice effects

SCDA performance is also a function of construction practices. Covering the holes and/or post-crack wetting have been recommended as variables to accelerate the process. However, these practices have actually been shown to retard initial cracking and increased time to reach crack width of 25.4mm [24].

3. CONCLUSIONS

SCDAs offer an alternative method for demolition of structures but have not been widely adopted, in part due to an inability for designers to model the expected response, as well as the proprietary nature of the material. With recently expired patents, new competitors are expected to emerge onto the market, and the usage of such products is likely to increase. SCDAs have proved suitable for demolition in the urban areas, due to their procedure being generally quiet, and involving only minimal vibrations. Moreover, in case of heritage buildings, where demolition needs to be confined to a small portion of the structure or to a shallow surface depth, SCDAs are more attractive than traditional demolition methods, as they are less intrusive. In light of increasing concerns for sustainable development, SCDAs are poised to gain further importance in demolition industry, but rigorous and extensive testing programs are needed for designers and owners to use them cost-effectively with full confidence.

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