Properties of Soundless Chemical Demolition Agents

By Jimmie Hinze[1] and James Brown[2]

Abstract: The traditional approach to demolish concrete structures or to reduce the sizes of large rocks or boulders has typically included the use of explosives. The resulting explosions are associated with the obvious risks posed by shock waves and fly rock. These, along with other detrimental side effects of using explosives, have increased an interest in the use of alternative methods to demolish rock and concrete structures. Soundless chemical demolition agents (SCDAs) have proven to be viable substitutes for the use of explosives. SCDAs are powdery materials that will expand considerably when mixed with water. This expansion, when occurring under confinement, generates significant expansive pressures. These pressures are sufficient to break up rock and concrete when the SCDA is confined in a borehole or a series of boreholes. Experiments have been conducted with SCDAs to learn more about those variables that tend to hamper or enhance SCDA performance. Results show that the amount of mixing water and the ambient temperature are the most important variables in influencing the generation of SCDA expansive pressures.

INTRODUCTION

Soundless chemical demolition agents (SCDAs) are lime-based products that have become recognized as viable substitutes for explosives in fracturing such materials as rock and concrete. While explosives are still common, interest in SCDAs is growing since they do not make noise, explode, or generate fly rock, vibration or toxic fumes. SCDAs are also safer than traditional explosives, which pose the threat of premature explosion and which may misfire, posing a significant threat after the planned explosion. Contrary to explosives, SCDAs produce their destructive forces in rock and concrete by generating significant expansive forces without generating shock waves.

SCDAs are similar to portland cement in their general appearance. A typical SCDA is essentially a grayish powdery substance consisting of primarily (typically over 90%) lime or CaO, and varying amounts of the following substances: aluminum oxide (Al_2O_3), magnesium oxide (MgO), ferrous oxide (Fe_2O_3), silicon (SiO_2) and calcium fluoride (CaF_2). Lime is the primary ingredient; the additives generally are included to alter, delay, enhance, or otherwise control the hydration of the SCDA. SCDAs are manufactured primarily in Japan, China, Russia, and some countries in Europe. There is no known commercial production of SCDAs in the United States.

The preparatory procedures involved in using SCDAs are similar to those followed in traditional blasting techniques. Specifically, boreholes must be drilled to contain the SCDA. Beyond this, however, the similarities diminish. The SCDA must be mixed with a measured quantity of water and poured

[1]Prof., Dept. of Civ. Engrg., 121 More Hall, FX-10, Univ. of Washington, Seattle, WA 98195.

[2]Christopher Brown Assoc., 879 Rainier Ave. N., Suite A201, Renton, WA 98055.

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into the boreholes. It will then begin to hydrate, generating heat and crystallizing while hardening and expanding. If hydration takes place under confinement, significant expansive pressures will result. The pressures can be of sufficient magnitude that, after a period of time, they will fracture the confining material. Depending on the type of SCDA, significant expansive pressures may be generated as quickly as within 15 min, or as long as within 24 hr.

While there are several advantages to using SCDAs, their relatively high cost makes explosives more cost-effective in many applications. Nonetheless, SCDAs have become a common means of breaking up boulders that have rolled onto remote mountain highways. SCDAs have also been used when excavating rock, or demolishing concrete structures or components of concrete structures near inhabited areas, natural gas lines, roadways or other areas where the use of explosives would pose a significant safety risk.

When using SCDAs, contractors generally rely on empirical information to produce a desired outcome. Though this has proven sufficient in many smaller applications, the question may still arise whether destructive potential is being optimized. Trade-offs must be made between the cost of labor and equipment for drilling the boreholes at a given diameter and at a given spacing, and the cost of the SCDA being used.

Technical data available on SCDAs is largely limited to the glossy brochures of manufacturers, which extol the attributes of a particular product. This information is typically limited to a single figure showing expansive pressure as a function of time with no other information regarding the means or conditions under which the measurements were made. The user must assume that field performance will replicate laboratory performance or make conservative adjustments based on experience and/or intuition. While the "technical data" may stress the importance of staying within a specified range of water content and ambient temperature to achieve desired expansive pressures, little information is given regarding the effect of using the SCDAs outside the stipulated ranges, and no information is provided regarding the effect of variations within these ranges. Recognizing this lack of information, the University of Washington has undertaken a series of experiments with the intent of quantifying SCDA performance characteristics, particularly those related to the sensitivity of SCDA performance to variations within the specified ranges of water content, ambient temperatures, and borehole diameter.

LITERATURE REVIEW

Although the use of explosives remains the principal means by which rock and concrete structures are demolished, there has been an increased use of SCDAs over the past two decades. The urbanization of America has been a driving force in the industry's efforts to find substitutes for traditional explosives. This has resulted in many demolition projects taking place in the vicinity of populated areas, locations where explosives often pose a significant threat to human safety (Schram and Hinze 1989). SCDAs provide one effective alternative to the use of explosives (Tarricone 1990).

Despite the considerable use of SCDAs over the past two decades, there is still little standardization surrounding the manufacture and use of SCDAs. In fact, there is not even a consensus as to the proper terminology by which reference should be made to SCDAs. Other terms by which SCDAs are known include soundless cracking agents, expansive agents, expansive concrete, nonexplosive demolition agents, and other related variations of these

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terms (Dowding and Labuz 1982; Kawano 1982; Kesler 1976). Similarly, there is no consensus as to the appropriate method by which to evaluate the actual performance of SCDAs under laboratory conditions. Test methods that have been proposed include the use of thick-walled cylinders, thin-walled cylinders, long cylinders, and even complex arrangements in which cylinders with attached strain gauges are inserted into the boreholes of larger cylinders (Gomez and Mura 1984; Harada et al. 1986; Ishibash et al. 1984; Watanabe et al. 1982).

Past researchers have tried to evaluate the performance of SCDAs. Unfortunately, these researchers did not all use the same test procedures (Gomez and Mura 1984; Harada et al. 1986; Mehta and Lesnikoff 1973; Polivka 1973; Watanabe et al. 1982). This has led to confusing, if not contradictory, results. Researchers have reported that temperature and water content in the SCDAs influence SCDA performance; however, these findings are largely inconclusive and they do not give succinct information about the degree to which these variables impact SCDA performance (Dressen 1986; Idemitsu and Takeda 1983; Mehta and Lesnikoff 1973; Polivka 1973).

RESEARCH METHODOLOGY

Tests were devised by which the generation of expansive pressures as a function of time could be carefully controlled while the influence of a given variable was being examined. The test that was employed for all experiments was selected because: (1) It had been proven to provide accurate information; and (2) it was relatively inexpensive. These experiments were conducted using steel cylinders, and the computation of expansive pressures was based on the principles of thick-walled cylinder theory (Boresi and Chong 1987; Roark 1965). Stress computations were made with the use of the following formula:

$$p_i = \frac{E\varepsilon(r_o^2 - r_i^2)}{2r_i^2} \tag{1}$$

where p_i = internal pressure (inside borehole); E = Young's modulus of cylinder material; ε = tangential strain on outside of cylinder; r_o = outside diameter of cylinder; and r_i = inside diameter of cylinder.

By utilizing the relationship between internal pressures and hoop strains, an economic and reusable system of thick-walled cylinders and externally mounted strain gauges was fabricated. The cylinders served to confine the SCDA in a manner replicating an actual borehole in the field, and the strain gauges facilitated direct monitoring of the expansive pressures as they developed over time. This procedure was developed at the University of Washington under a grant from the National Science Foundation, and was successfully used in numerous experiments. The accuracy of this procedure was validated by recording strain gauge measurements as test cylinders were filled with hydraulic fluid and subjected to various known pressures.

A total of six cylinders were fabricated, each measuring 100 mm in height (see Fig. 1). Three cylinders had 25 mm diameter boreholes, and three cylinders had borehole diameters measuring 38 mm, 43 mm, and 50 mm. Wall thicknesses ranged from 22 mm to 32 mm, the cylinders with larger boreholes having the thicker walls. Wall thickness of this magnitude was considered vital to the success of the experiments because the mass of the metal in each cylinder would effectively absorb a significant amount of the heat of hydration and dissipate the heat so that strain gauge performance

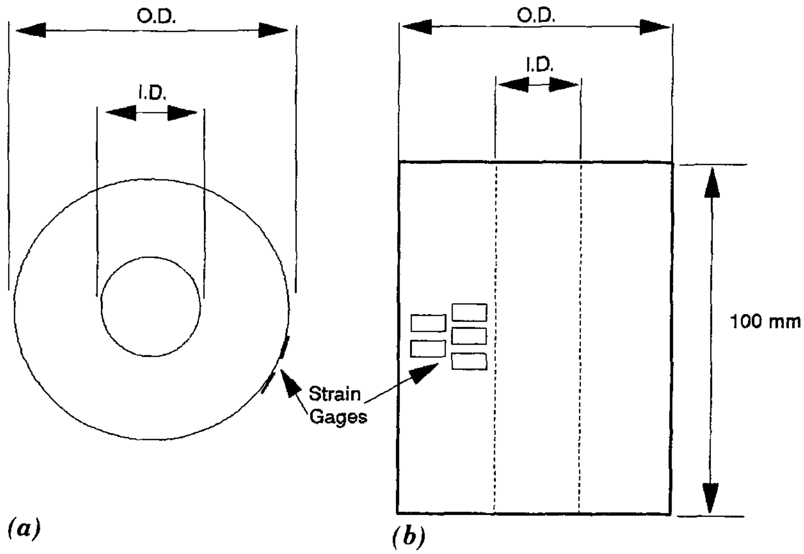

FIG. 1. Typical Test Cylinder Configuration: (a) Top View of Typical Cylinder; (*b*) Elevation of Typical Cylinder

was not compromised. Note that this heat dissipation would also be expected to occur in field conditions. It has been noted in earlier experiments that the heat of hydration could cause temperatures of the SCDA to exceed 150°C. At this temperature any free water in the SCDA mixture would be transformed to superheated steam, which could provide sufficient pressure to expel some of the SCDA mixture from the borehole. Although temperatures were not monitored during testing, the mass of the cylinders apparently dissipated the heat sufficiently so that no problems were encountered.

Each test cylinder was fitted with five quarter-bridge strain gauges clustered near the center of the cylinder parallel to the circumference line (see Fig. 1). Grouping the gauges in this manner facilitated measurement of hoop strains without interference from "end effects." It is near the ends of the test cylinders where the SCDA is least confined, and may possibly result in spurious strain gauge readings. The general configuration is shown in Fig. 1.

Since different SCDAs exhibit slightly different characteristics (e.g. rate of hydration), analysis was limited to a single brand. The material chosen for this analysis was a fast-acting SCDA of Chinese origin, capable of producing significant pressures in 5–6 hr, with pressures approaching maximum within 24 hr. The sole basis for selection was the rapid rate of hydration, since several tests could be run in a short period of time. The manufacturer of this particular SCDA specified a water/SCDA ratio of 30–34% (1.5–1.7 L/5 kg), and an ambient temperature range of 20–35°C. A borehole diameter of 43 mm was recommended, i.e., no range of acceptable borehole diameters was given.

As noted earlier for the SCDA used in the experiments, SCDA manufacturers often provide brochures with specific instructions on how to prepare the SCDA slurry. They also stress the importance of staying within a specified range of water content and ambient temperature to achieve expansive pressures as advertised. Little information is given regarding the effect of using the SCDAs outside of these ranges, and no information is provided regarding the effect of variations within these ranges. The purpose of this analysis, therefore, was to determine the sensitivity of SCDA performance to variations within the specified ranges of water content, ambient temperature, and borehole diameter.

Care was exercised when combining the SCDA with the water because thorough mixing is needed for effective hydration. Mixing began by measuring the requisite proportions of SCDA and water in separate containers. Then, while gently stirring the SCDA with a blending attachment on an electric drill, the water was slowly added. Stirring then continued at full speed for about 30–45 sec until a smooth, milk shake or malt-like consistency was achieved. The slurry was then poured into the boreholes of the test cylinders until the entire volume was occupied by the SCDA. A steel plate was then placed over the borehole and lightly clamped down. The SCDA was then allowed to hydrate for the remainder of the test without disturbance.

Since manufacturers typically recommend a borehole diameter of 43 mm, an investigation was conducted to determine the extent of variability in SCDA performance when variations occurred in borehole diameters. This was accomplished by running a test at a constant 33°C using the different sized (25, 38, 43, and 50 mm) cylinders. Each cylinder was filled with a uniform SCDA mix containing 32% water.

The various experiments conducted on SCDA performance were closely monitored to ensure that only one variable changed at a time. One aspect of SCDA performance that was examined was the influence of the amount of water on pressure generation. Sensitivity to variations in water content was examined by using water/SCDA ratios of 30%, 32%, and 34%, which covered the manufacturer's recommended range. This test was conducted while maintaining a temperature of 33°C, and utilized cylinders with 25-mm borehole diameters.

Another variable in the experiments of considerable interest was that of ambient temperature. Laboratory conditions were controlled so that SCDA performance would be evaluated at different temperatures. Thermal sensitivity was determined by performing tests at both 20° and 30°C, approximately covering the recommended temperature range. An additional test was run at 45°C to determine the effect of exceeding the recommended range. These tests were run utilizing a 33% water/SCDA ratio and the cylinders with the 25-mm borehole diameters.

A final test was run in order to observe the combined effect of water content and temperature. This test consisted of a series of experiments. The intent of this test was to demarcate the upper and lower limits of expansive pressure variations possible within the manufacturer's stated ranges. Each experiment was run using the cylinders with 25-mm diameter boreholes. In one experiment, a test cylinder was filled with an SCDA mixture of 30% water, while another cylinder was filled with a mixture containing 34% water. This test was run at a temperature of 34°C. In another experiment, one cylinder was filled with an SCDA mixture of 34% water, while another cylinder was filled with a mixture containing 30% water. This experiment was run at a temperature of 22°C. The different tests are summarized in Table 1.

RESULTS

As the tests were conducted, the heat of hydration was evident from the increased temperature of the steel cylinders. While the temperature rise

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TABLE 1. Summary of Tests Conducted

Test number (1)	Water/SCDA ratio (%) (2)	Ambient temperature (°C) (3)	Figure presenting the results (4)	Primary purpose of the test (5)
1	31	25	Fig. 2	Present the general characteristics of generating expansive pressure with SCDAs as a function of time
2	32	33	Fig. 3	Demonstrate the generation of expansive pressures with different borehole diameters
3	Varies	33	Fig. 4	Demonstrate the generation of expansive pressures with different water/SCDA ratios
4	33	Varies	Fig. 5	Demonstrate the generation of expansive pressures at different ambient temperatures
5	Varies	Varies	Fig. 6	Demonstrate the generation of expansive pressures with different combinations of ambient temperature and water/SCDA ratios

was not substantial, it was noticeable to the touch. Although the temperature was not monitored as part of this series of experiments, the influence of the rise in temperature in the early stages of testing was apparent. It was noted in the first few hours of testing that the strain gauge readings were frequently negative or erratic. Meaningful readings could be recorded only after the measurements of the various strain gauges had stabilized and were consistent. Because of the heat of hydration and its effect on the electrical resistance of the strain gauges, data in the first hours after pouring were quite spurious and therefore omitted from the plotted data. Since reliable measurements were not available in the initial periods of testing, the pressure-time curves presenting the results of the experimentation begin at some time after time "zero."

Each of the figures to be presented should be viewed as a singular test. Because of the number of variables that can influence SCDA performance, it would be inappropriate to compare the results of different tests.

The strains were recorded from the five strain gauges, and the average of these values was used to compute the magnitude of the expansive pressure as it developed within the boreholes. A typical presentation of the development of expansive pressures as a function of time is shown in Fig. 2. Once the expansive pressures began to develop, they increased at a relatively fast rate. Note in the test presented in Fig. 2, after 15 hr the expansive pressure exceeded 20 MPa. The expansive pressure continued to increase thereafter, but at a diminished rate. After 24 hr, the expansive pressure was about 25 MPa. Since SCDAs break up rock and concrete by exploiting their relatively low tensile strengths, it is apparent that significant destructive pressures are attained in the period of 1 day.

The results of a test conducted with SCDAs in cylinders of differing diameter boreholes are shown in Fig. 3. It was suspected that the primary difference between the tests was in the amount of SCDA required to fill the boreholes. Those cylinders with the larger boreholes would contain more

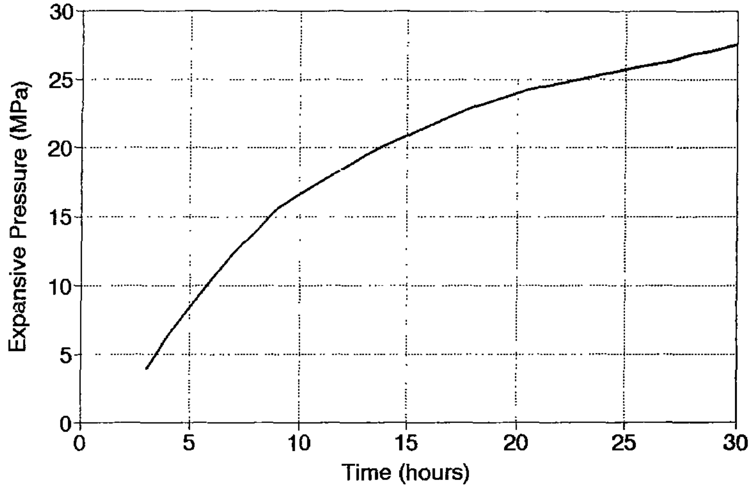

FIG. 2. Development of Expansive Pressure as Function of Time

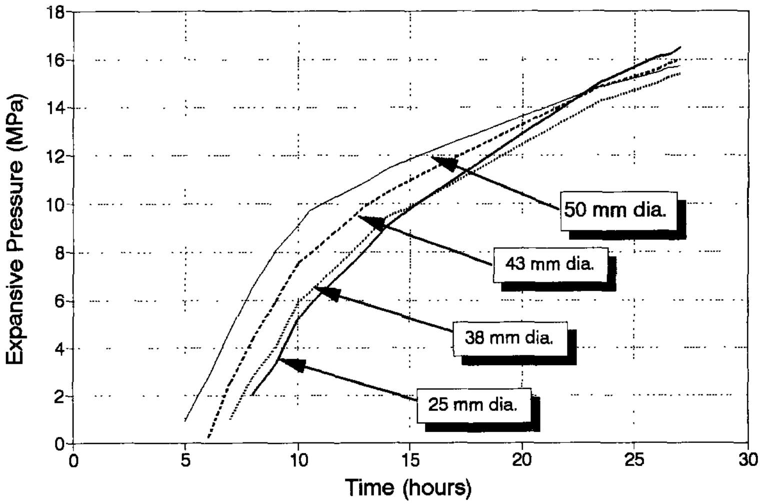

FIG. 3. Expansive Pressures Resulting With Different Borehole Diameters

SCDA and, as a result, would be expected to hydrate more quickly. This is due to the nature of SCDAs, which hydrate faster at elevated temperatures. There is an increase of SCDA in the large boreholes and a decrease in metal mass to absorb the heat. This would cause the greater quantity of SCDA to serve as a heat sink, in that the heat of hydration would not dissipate as rapidly as in the cylinders with smaller diameter boreholes. This elevated temperature, caused by the hydration, would enhance or accelerate the hydration process in the larger borehole cylinders.

As shown in Fig. 3, the hydration does appear to be more rapid in the larger boreholes as demonstrated by a quicker development of expansive pressures. It was interesting to note that the expansive pressures generated by the different cylinders tend to converge to a common point, in this case, at about 15 MPa after 24 hr. Fig 3 shows that the larger boreholes developed expansive pressures earlier than smaller ones. Despite this measurable difference, the initial rates of pressure generation did not vary excessively between the different cylinders. The pressure-time curves appear to indicate that the expansive pressures generated within the smaller diameter boreholes may continue to increase to levels in excess of those levels attained by the larger diameter boreholes. Since users of SCDAs generally expect to demolish rocks and concrete within 24 hr, it was not deemed valuable to explore the ultimate pressures that are attained with the different borehole diameters.

The recommended range of water content to be used with the SCDA being tested was 30–34%. If too little water is used, there will be insufficient water to properly hydrate all the SCDA. If excess amounts of water are used, free water will remain in the slurry and this may compromise SCDA performance. Experiments were conducted with SCDA slurry with water contents of 30%, 32%, and 34%. Fig. 4 shows that there is an inverse relationship between the amount of water used and expansive pressure that is generated. In this experiment, an increase in water content from 30% to 34% resulted in approximately a 33% lower attained 24-hr expansive pressure. The performance of the 32% water/SCDA slurry was approximately in the midrange of the observed performance. Although the 30% water/SCDA slurry performed quite well, it was noted that this mixture was quite thick, making it difficult to easily pour the slurry into the boreholes. In terms of handling or workability, the 30% water/SCDA slurry was approaching the limit of how thick the slurry could be before it was unworkable.

A series of three tests was conducted to assess the influence of ambient temperature on SCDA performance. The temperatures were 20, 30, and 45°C. SCDA performance was found to be quite sensitive to changes in ambient temperature, as shown in Fig. 5. Expansive pressures began to develop slowly at 20°C, with the expansive pressure attained after 24 hr

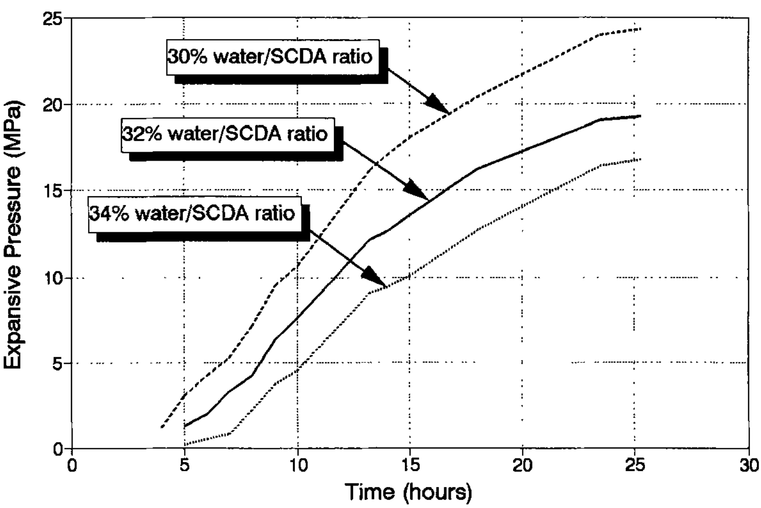

FIG. 4. Expansive Pressures Resulting at Different Water/SCDA Ratios

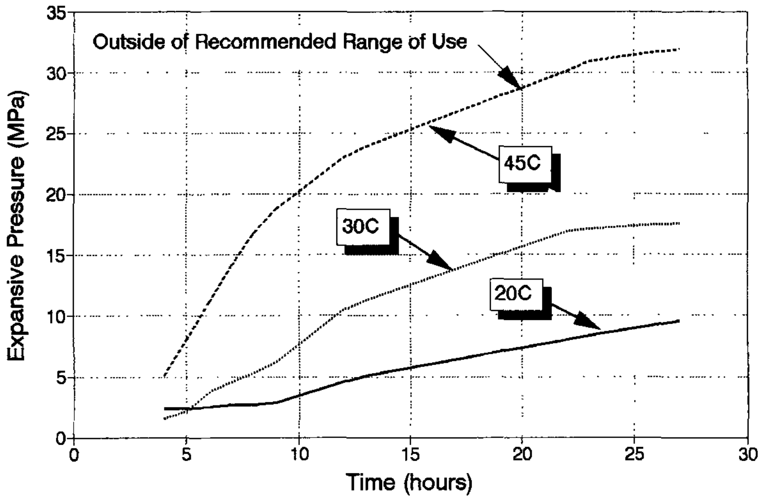

FIG. 5. Expansive Pressures Resulting at Different Temperatures

being relatively low, less than 10 MPa. At 20°C the 24-hr pressure was about one-half the pressure generated at 30°C and about one-fourth of the pressure generated at 45°C. The trends in pressure development were well established within the first 10 hr of the test, and remained consistent throughout the test. It should be emphasized that the recommendations of the manufacturer were that this material was not to be used at an ambient temperature that exceeded 35°C. It appeared that this limit was imposed as a safety precaution to avoid the increased potential of spewing the SCDA from the borehole. While this note of caution was recognized, there were no unusual incidents associated with the SCDA being used at the elevated temperature, other than the noticeably increased generation of expansive pressures.

Since the variables that influenced SCDA performance to the greatest extent appeared to be ambient temperature and water content in the SCDA slurry, a series of tests was conducted to determine the influence on pressure generation when both water content and ambient temperature were manipulated. The tests essentially examined SCDA performance when ambient temperatures were at the low and high extremes of recommended use and the water content of the slurry was at either the high or low extreme of recommended use. The results of these tests are shown in Fig. 6. Based on previous test results, one would expect that a low water/SCDA ratio coupled with a high ambient temperature would yield pressures markedly higher than any other combination. This indeed was the case, since at 20 hr, the mix containing 30% water and tested at an ambient temperature of 34°C yielded pressures of about 34 MPa, 14 MPa higher than the 34% mix tested at 22°C. The pressures yielded by the 30% slurry tested at 22°C, and the pressures generated by the 34% slurry tested at 34°C fell in the middle of the extremes.

CONCLUSIONS

The results of the controlled laboratory experiments of SCDA performance provide clear evidence that borehole diameter does not appear to be a significant variable when the SCDA is used in boreholes ranging from

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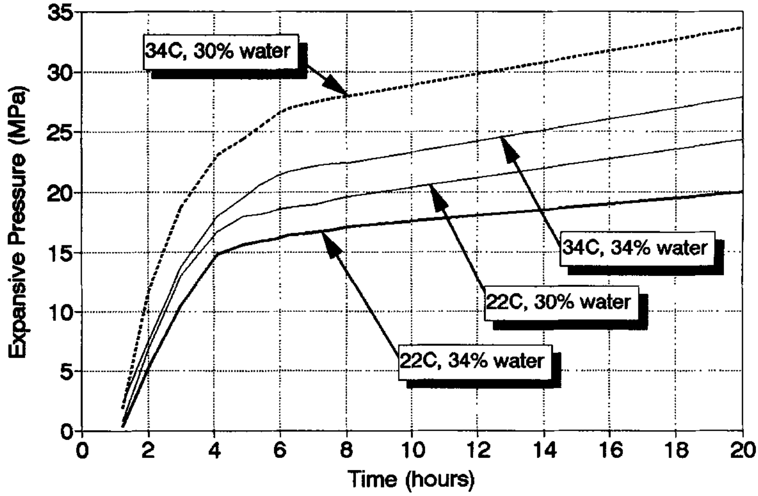

FIG. 6. Expansive Pressures Related to Changing Temperatures and Water Content

25 to 50 mm in diameter. At the start of the test, expansive pressures increased at a more rapid rate in larger borehole cylinders. This may have been caused by the reduction in metal mass in the larger borehole cylinders. The expansive pressure attained after 24 hr appeared to be essentially the same for all borehole sizes.

SCDA performance is influenced to a considerable degree by the water/SCDA ratio. While the recommended water content ranged from 30% to 34% the expansive pressures attained after 24 hr varied by more than 25%. The lower water content in the SCDA mixture consistently provided the higher expansive pressures.

Ambient temperature was found to be the most significant variable to influence the generation of expansive pressures. While the recommended range of ambient temperature for the SCDA being used was from 20° to 35°C, tests showed the higher temperatures yielded even greater expansive pressures.

Tests in which both ambient temperatures and water/SCDA ratios were examined revealed that there is considerable sensitivity of SCDAs to variations in these parameters. Results indicate that ambient temperature has a slightly greater influence on pressure development, but that the influence of water content is also considerable. The highest expansive pressures were generated when the water content was low (30%), and the temperature was high (34°C).

The laboratory experiments have shown that the technical information provided by the manufacturers appears to represent SCDA performance under ideal conditions, particularly of optimum temperature and water content. The information presented in the manufacturers' brochures does not indicate that the SCDA performance is subject to considerable variation when used within the recommended ranges of ambient temperature and water content.

RECOMMENDATIONS

Given the thermal sensitivity of SCDAs, the temperature of the confining material requires careful consideration. If the temperature of the confining material is near the lower end of the recommended range, it may be necessary to reduce borehole spacing. If the temperature is warm, the boreholes can be spaced farther apart, but very high temperatures increase the risk of a blowout. A blowout may occur when the confining material fails to dissipate the heat of hydration and results in a sudden spewing out of the slurry. This phenomenon requires additional investigation.

Since expansive pressure is inversely proportional to the water/SCDA ratio, low-water mixtures perform best. Mixtures with smaller quantities of water (below about 30–31% water), however, should be avoided because they are too stiff to pour and may cause the formation of air pockets in the boreholes, reducing SCDA performance.

This analysis showed little difference between the 24-hr expansive pressures of different borehole diameters. Hence, it is suggested that the type and cost of the SCDA be balanced between the cost of drilling, the type of material being removed, and borehole spacing.

With a heightened awareness of SCDA behavior, a user should be better able to estimate the expansive pressures that will probably be realized under a given set of conditions. This will aid in determining the applicability and amount of SCDA required for a particular application. It will also allow for more effective use of the SCDA benefits over conventional blasting techniques.

Current practice in the use of SCDAs relies heavily on the literature provided by the manufacturers of SCDAs. When the performance characteristics of SCDAs are described, information should be provided that will be useful to the end user. First, information should be provided concerning the methods used to measure the expansive pressures generated by the SCDAs. Second, the performance of each SCDA should be clearly described. A family of expansive pressure versus time curves may be most appropriate to accurately describe the performance of a particular SCDA under varying conditions, particularly as variations occur in the ambient temperature and in the water content of the slurry.

Last, additional testing of SCDAs should take place to learn more about the means by which SCDAs actually function to break up rock and concrete. Some basic information has been obtained, but additional information should be sought concerning the reliability with which laboratory test information can be effectively applied under field conditions.

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