Economics of Lithium Technology for ASR Control vs. Alternatives

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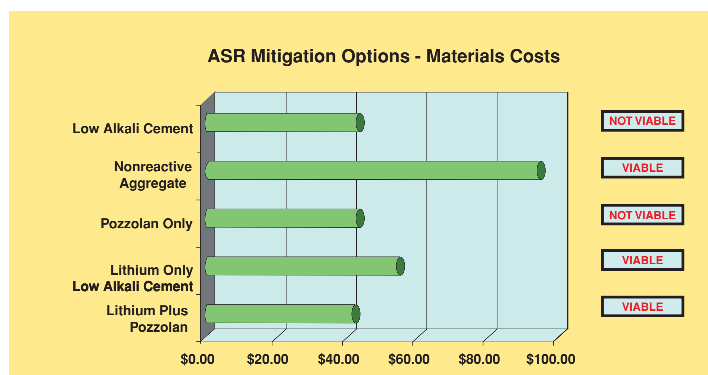
Concrete durability, and more specifically Alkali Silica Reactivity (ASR) is fast becoming an item of great concern to owners following research conducted under the Strategic Highway Research Program (SHRP) and more recently the Innovative Pavement Research Foundation (IPRF). Even though the issue of ASR has been around for several decades this research has shown that traditional ways to address the issue were not as effective as originally thought, and field evidence of ASR occurrences in concrete have proven this, resulting in agencies and owners having to modify their specifications incorporating new technologies to minimize the risk of ASR.

Why is this of concern to the ready mixed producer? After all, ASR does not show up as cracking and expansion for years, considerably after the concrete has been placed and paid for by the owner. To quote JC Roumain, Holcim Cement, "The biggest competitive threat to concrete is BAD concrete." In other words, if the concrete placed does not meet the design life expectancy, or if the concrete placed requires significantly more maintenance than planned, then the life cycle cost arguments that clearly show that concrete is the material of choice become suspect, and force the owners to seek alternatives. One of the first steps taken is to change the specifications by requiring tighter testing procedures, but allowing options on how to meet the standards. One of the new options that is appearing in a number of specifications is the use of lithium admixtures. Since this is new, it is a largely unknown option thus very difficult to evaluate with regards to developing bids utilizing this option. In addition, the rumor in the marketplace is that lithium is "too expensive". As a consequence a producer is too often likely to ignore this option and bid using better known options, at times ending up losing the bid to a more savvy producer who took the time to fairly evaluate all options and realized that the lithium option is not only an economical option, but at times the lowest cost option available to meet the specification requirements. It is the purpose of this article to dispel rumors regarding lithium technology and assist the producer in fairly evaluating options available to meet ASR requirements, and producing bids that will be competitive and profitable.

According to state-of-the-art specifications, the options available for ASR mitigation are:

1. Use of non-reactive aggregates;
2. Use of suitable pozzolans;
3. Use of lithium admixtures; and
4. Use of combinations of pozzolans and lithium.

ASR Options Calculator Spreadsheet



Example of Comparative Chart from ASR Calculator

While obviously not exhaustive, these examples demonstrate that lithium technology is a practical, economically viable alternative that should be considered when allowed in spite of its reputation of being "too expensive". Like all other new technologies, the reputation came from the fact that it is difficult to understand the cost of the technology without having considered all aspects, and providing a means to evaluate its cost compared to the other alternatives available. The purpose of this paper is to dispel these rumors and provide the ready mixed producer a better understanding of how to evaluate relative costs and make the best economical decisions in the bidding process.

In the new specs, these options must pass tests that are specified, which are usually modifications of ASTM C 1260, *Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method).* When deicing compounds are used that are salts of sodium or potassium, such as on airfield pavements, additional testing requirements may include a further modification of this test that incorporates the deicer in the soak solution used in the test. A number of researchers recommend that ASTM C 1293, *Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction,* be used to evaluate mixes, but this test takes two years for the results and therefore is not practical for construction purposes and, even though allowed on some specifications, it is very seldom adopted.

A traditional way of combating ASR was to utilize low alkali cement at below 0.6% sodium oxide equivalent (Na_2O eq.). Over the years it has become apparent that this approach did not work as effectively as was previously thought. The important parameter should have been total alkali of a mix rather than the alkali percentage of the cement component. In addition, this approach cannot compensate for external sources of alkali such as some deicing salts. In some areas where very low alkali cements are available (e.g. 0.4% Na_2O eq. or lower), and the aggregates are moderately to mildly reactive and there are no sources of external alkali, this approach is still a viable option.

When the ready-mix producer is faced with having to bid on a project with specifications for ASR allowing those options, care should be taken in evaluating and costing out each option prior to submitting a bid. This evaluation may take some effort at first, but once the producer has determined his costs using locally available materials, this evaluation becomes significantly easier for future bids. This evaluation will improve the chances of winning the bid based on the most economical option for the particular job, and allows the producer to increase his/her margins by minimizing risk and variability encountered when actually producing a job. Let's examine what the cost factors are with each option.

1. Use of non-reactive aggregates (both coarse and fine)

This sounds like an obvious solution, however tests have gotten tougher over the years so that some aggregates that historically passed the tests are now deemed to be potentially reactive. Historical data for a particular aggregate is proving, at least in some instances, not to be a reliable indicator due to changes in the aggregate characteristics in different parts of a quarry. Availability of non-reactive aggregates has also decreased over time, as their use was preferred in the past. Since reactivity of the aggregate is due to its mineralogy, it is unlikely that if a particular aggregate were determined to be potentially reactive other aggregates from nearby sources would test as non-reactive. In many cases, non-reactive sources may need to be imported from distant locations. Cost of transportation of aggregates must be taken into account and at present fuel prices this can significantly impact the total cost. The producer must bear in mind that trucks must get to the aggregate supplier empty and return full, thus transportation costs must be figured at twice the distance. In addition, the cost of the aggregates will most likely be higher if they are not from the standard supplier or the producer's quarry, and provisions must be made to isolate the nonreactive aggregate from the aggregate normally used at the plant. Finally, in most cases it is prudent to test your mix with the new aggregates and adjust accordingly to avoid any potential production issues.

2. Use of suitable pozzolans

The most common pozzolan that can be used to prevent ASR is fly ash. However, not all fly ashes are alike. The most suitable ashes are Class F fly ashes with a low lime (less than 8% CaO) content. In most cases Class C fly ash is not acceptable or allowed. When using Class F ashes with a medium to high lime content (e.g. greater than 8%) testing must be conducted and the amount needed may be so high as to cause real issues in set time, strength gain and in obtaining the necessary amount of air in the mix (mostly dependent on the LOI of the ash). In addition, due to recent changes in the Clean Air Act that resulted in changes that power plants had to make in order to meet the new regulations, availability of good Class F ash has been decreasing and is more difficult to get. Pricing of good quality Class F ash has also been increasing due to demand outstripping supply. The amount of Class F ash needed is based on the reactivity of the aggregates and should be determined by testing.

Ground granulated blast furnace slag (GGBFS) may not be an option in cases where it is not readily available or the amount needed is too high to combat ASR where the new deicer ASR testing is used for airfield pavements (See Northwest Mountain Region Federal Aviation Administration specification P-501, modified June, 2006), scaling is an issue or there are concerns with finishing and curing concrete if not handled properly.

Silica fume can be effective, however, care must be taken to ensure proper mixing and dispersion in the mix because clumps of silica fume in a mix can be the cause of ASR. Price of silica fume is also higher than cement, thus its use will in most cases increase cost significantly.

Natural pozzolans can be very effective, but their availability is very scarce throughout the US. If a pozzolan is used, in order to fully evaluate the costs the producer should ensure availability, determine if a silo is available for the material or make arrangements for one to be installed, and mix design testing should be conducted.

3. Use of lithium admixtures

Lithium admixture (nominal 30% lithium nitrate solution) can be used with any aggregate source and allows the use of any local materials. Amount of admixture needed is based on the alkali content of the mix from the cement. Manufacturer recommendations for most aggregates is 0.55 gallons of admixture for each pound of alkali supplied in a cubic yard of concrete, so the amount needed is based on both the quantity of cement used and the alkali content (Na_2O % equivalent in the mill report). This is referred to as the 100% dosage. Certain aggregates may require more than the 100% dosage, which can be ascertained by conducting the required testing. Using low alkali cement can minimize cost for this option. Lithium can be added as any other admixture and in most cases addition of lithium will have minimal effect on the properties of the mix except for a slight acceleration of setting time. Care must be taken to ensure that according to manufacturer recommendations, 0.85 gallons of water must be removed for each gallon of admixture added to maintain the proper w/c ratio.

4. Use of combinations of pozzolans and lithium

This option combines the good qualities of both of the other options while reducing the cost of the mix. In general, it is possible to substantially reduce the amount of lithium needed in the mix by using it in combination with a suitable pozzolan. The most common practice is to use it in combination with Class F fly ash. The concept is to maximize the amount of Class F fly ash used while meeting needed set times and strength gain requirements, then top it off with lithium to achieve the desired ASR testing results. As a guideline, dosage can be reduced to 52% of the dosage when the mix includes 25% (by weight of cementitious materials) low CaO content Class F fly ash. Lithium dosage is also decreased by the fact that it is calculated on the basis of portland cement; therefore it is lowered by the fact that a portion of the cement was replaced with the pozzolan.

It is possible to design a mix incorporating Class C fly ash by the addition of lithium; however with most Class C fly ashes the lithium dosage will have to remain at 100% and in fact can be higher than the standard dosage. Of course in these cases the amount of lithium will be decreased by the fact that the mix will have lower cement content. Testing must be conducted in order to determine if a mix with Class C fly ash is a real option with locally available materials.

Lithium can also be used in combination with silica fume, though due to price of silica fume this is mainly applicable only to bridge decks. No testing has been conducted on the use of lithium in combination with GGBFS, so testing must be conducted in order to determine if lithium dosage can be decreased.

So how do you put all the information together and develop figures for cost of the mix for the different options so you can decide how to bid a particular project? Let's look at a couple of examples and work through them to demonstrate the methodology. The figures in these examples are fictitious for illustrative purposes only - so you should adjust the figures to reflect your actual costs of materials and manufacturing. The actual bid price should be established based on other costs and anticipated margin. While the examples are based on actual recent specification requirements, any reference to a specific project should be avoided and is not implied. Each circumstance and each job will be different.

1.) Example 1 – Pavement in a southern state.

Requirements – Mix must meet ASTM C 1567, *Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)*, testing with a maximum expansion of 0.10% at 14 days. (This procedure is a modification of ASTM C 1260 that evaluates cementitious aggregate combinations.) Standard mix requires 6.5 sacks of cement (611 lbs) for the desired strength at 0.45 w/c. The project has tight timelines and penalties for lateness. The four options discussed above are allowed. Class C fly ash is not allowed.

Note: Both aggregates (coarse and sand) you have available are marginally reactive as measured by ASTM C 1260 at 14 days. The cement you have available is low alkali cement at 0.48% Na_2O eq.. You have a silo for fly ash, which presently holds Class C fly ash. A good low lime (5.0% CaO) Class F fly ash is available.

Your standard mix (without the Class C fly ash) for 6.5 sacks is as follows:

	Quantity	Unit Cost	Cost/cu yd
Cement	611 lbs	$ 86.00/ton	$ 26.27
Coarse agg	1884 lbs	$ 7.00/ton	$ 6.59
Sand	1541 lbs	$ 6.00/ton	$ 4.62
Admixtures, etc.	$ 0.50		
Material waste	2.5 %	$ 0.95	
	Total	$ 38.93	

Assume that the following are your additional costs/cu yd		
Interest on money (90 day pay, 6.0 % PA)$0.58		
Operating costs		$3.00
Delivery cost	(20 miles)	$3.00
Fixed/Capital costs		$20.00
	Subtotal	$26.58
	Total cost per cu yd	$65.51

Option 1 - Nonreactive aggregate

Estimate your transportation cost. Excellent rates from a common carrier currently run around $ 0.20/ton/mile on the low end. For a captive truck fleet to carry out the hauling, this cost should include fuel cost (minimum of $ 0.035/ton/mile), cost of a driver, and amortization of truck, taxes, insurance, maintenance cost and a usage factor. A conservative estimate is $ 0.12/ton/mile.

The closest source of nonreactive coarse aggregate you find is 45 miles (90 miles roundtrip). Since it is a new source your cost is $ 9.50/ton. Therefore your coarse aggregate cost becomes:
(Amount of aggregate x cost of aggregate) + (transportation cost x distance)
(1884 lbs x (9.50/2000)) + (1884 x (0.12/2000) x 90) = 8.95 + 10.17 = $ 19.12

The closest source of nonreactive sand you find is 55 miles (110 miles roundtrip). Since it is a new source your cost is $ 7.25/ton. Therefore your sand cost becomes:
(1541 x (7.25/2000)) + (1541 x (0.12/2000) x 110) = 5.58 + 10.17 = $ 15.75

Finally your operating costs would increase an estimated $ 0.50/cu yd if you take into account that you will have to store and manage separate piles of aggregates.
So if you total in the changes

	Quantity	Unit Cost	Cost/cu yd
Cement	611 lbs	$ 86.00/ton	$26.27
Coarse agg	1884 lbs		$19.12
Sand	1541 lbs		$15.75
Admixtures, etc.			$0.50
Material waste	2.5 %		$1.54
	Total		$ 63.18

Assume that the following are your additional costs/cu yd		
Interest on money (90 day pay, 6.0 % PA)		$0.95
Operating costs		$3.50
Delivery cost	(20 miles)	$3.00
Fixed/Capital costs		$20.00
	Subtotal	$27.45
	Total cost per cu yd	$90.63

Option 2 - Use of suitable pozzolans

Your price for Class F fly ash is $ 65/ton delivered. You can only pass the ASR testing using 30% ash substitution. At this level you cannot obtain the strength using 1:1 substitution, therefore you have to resort to 1.2 lbs of fly ash for each pound of cement replaced. Since the testing showed that to control ASR you needed 30% by weight of cementitious materials; the amount of fly ash you will need is 611 x 0.3 = 183 lbs, the amount of cement in the mix will be 611 – (183/1.2) = 459 lbs cement.

In addition, you do not have a silo so you must install a new silo adding to the fixed/capital costs. You also need to plan to increase the amount of air-entraining admixture to maintain air.

Your costs can be expected to be as follows:

	Quantity	Unit Cost	Cost/cu yd
Cement	459 lbs	$86.00/ton	$19.74
Class F Ash	183 lbs	$65.00/ton	$5.95
Coarse agg	1884 lbs	$7.00/ton	$6.59
Sand	1541 lbs	$6.00/ton	$4.62
Admixtures, etc.			$1.00
Material waste	2.5 %		$0.95
		Total	$38.85

Assume that the following are your additional costs/cu yd		
Interest on money (90 day pay, 6.0 % PA)		$0.58
Operating costs		$3.00
Delivery cost	(20 miles)	$3.00
Fixed/Capital costs		$21.00
	Subtotal	$27.58
	Total cost per cu yd	$66.43

Option 3 - Use of lithium admixtures

Use a price of $ 15/gal as a budget price. This is a figure used by owners in recent RFP documents, which allow lithium. This figure does include a fair margin for the ready mixed producer. Actual pricing is dependent on quantity and location for freight from manufacturing sites. Product is readily available nationwide. To calculate amount needed:

611 lbs cement x 0.48% Na_2O equivalent x 0.55 gals = 1.6 gals of 30% lithium nitrate solution

Use of lithium allows the use of the local aggregates, does not affect properties of the mix, and will not require any capital investment (material storage and feeding systems supplied by the admixture company).

	Quantity	Unit Cost	Cost/cu yd
Cement	611 lbs	$86.00/ton	$26.27
Coarse agg	1884 lbs	$7.00/ton	$6.59
Sand	1541 lbs	$6.00/ton	$4.62
Lithium	1.6 gal	$15.00/gal	$24.00
Admixtures, etc.			$0.50
Material waste	2.5 %		$1.55
		Total	$63.53

Assume that the following are your additional costs/cu yd		
Interest on money (90 day pay, 6.0 % PA)		$0.95
Operating costs		$3.00
Delivery cost	(20 miles)	$3.00
Fixed/Capital costs		$20.00
	Subtotal	$26.95
	Total cost per cu yd	$90.48

Option 4 - Use of combinations of pozzolans and lithium

In this combination, the ASR tests can be met by lowering the Class F fly ash needed to 25% of the cementitious material and topping off with a reduced amount of lithium. At this level of ash when combined with lithium the strength gain requirements can be met using 1:1 substitution of cement. The amount of lithium required is expected to be 52% of the 100% dosage, even though testing should be conducted to confirm this. To determine the amount of lithium needed first calculate the amount of Class F fly ash used in the mix which will be 611 x 25% = 153 lbs of ash. From that determine amount of cement, 611 – 153 = 458 lbs. Then use the formula with the reduction factor to calculate the amount of lithium:

458 lbs x 0.48 % alkali x 0.55 gals/lb alkali x 52% reduction = 0.63 gal lithium

Your costs can be expected to be as follows:

	Quantity	Unit Cost	Cost/cu yd
Cement	458 lbs	$86.00/ton	$ 19.69
Class F Ash	153 lbs	$65.00/ton	$4.97
Coarse agg	1884 lbs	$7.00/ton	$6.59
Sand	1541 lbs	$6.00/ton	$4.62
Lithium	0.6 gal	$15.00/gal	$9.45
Admixtures, etc.			$1.00
Material waste	2.5 %		$1.15
		Total	$ 47.47

Assume that the following are your additional costs/cu yd		
Interest on money (90 day pay, 6.0 % PA)		$0.71
Operating costs		$3.00
Delivery cost (20 miles)		$3.00
Fixed/Capital costs		$21.00
	Subtotal	$ 27.71
	Total cost per cu yd	$75.72

Summary

In this example, it is clear that if all the other requirements of the job can be met with the use of the Class F fly ash, then this alternative is the most cost effective (Option 2). However, it can also be seen that if you go with straight lithium admixture the cost would be approximately the same as using non-reactive aggregate. The combination of pozzolan and lithium is significantly less than the use of non-reactive aggregates. This is generally true if the aggregate has to be transported any distance. In fact in this example if you work though the numbers this is true if the aggregates have to be transported 10 miles or more.

When would using lithium be a better option overall? In some cases, the lithium is a separate line item that can be charged separately. In these cases it can be seen that the combination of pozzolan and lithium is the most cost effective alternative, and your margin would be larger because of the additional margin to be gained from the lithium at the budgeted price. What would be the best alternative if no Class F fly ash were available? In this case it probably would be the lithium alone, because there are other advantages to using your standard supply of aggregates, you can better predict how the mix will perform, and you have the built in margin for the lithium.

2.) Example 2 - Airfield pavement in the Midwest

In this example the basic mix is based on 7.5 sacks of cement for strength gain at 0.4 w/c. ASR testing requirements include passing a modified ASTM C 1260 at 28 days at 0.1% expansion, and the new experimental deicer evaluation test[1] (a modification to C 1260 whereby the bar is immersed in deicer solution). The strength requirements are for 7-day flexural strength of 650 psi. The job has strict timetables and significant penalties for delays. No Class C fly ash or GGBFS are allowed. All four options previously discussed are allowed. Lithium is paid separately at a budget price of $ 15 / gal.

Note: all materials available and costs are the same as the first example, except that the Class F fly ash available has moderately high lime content (e.g. > 7.5%). Testing indicates that with locally available allowed pozzolans, no mix with straight pozzolan will pass both the flexural strength requirements and the ASR testing. Real options are: 1) non-reactive aggregates, 2) lithium, 3) combination of lithium with Class F fly ash.
Using the same methodology as above the following are the relative costs:

Option 1 - Non-reactive aggregate

	Quantity	Unit Cost	Cost/cu yd
Cement	705 lbs	$ 86.00/ton	$ 30.32
Coarse agg	1874 lbs		$19.01
Sand	1533 lbs		$15.68
Admixtures, etc.			$0.50
Material waste	2.5 %		$1.64
		Total	$ 67.15

Assume that the following are your additional costs/cu yd		
Interest on money (90-day pay, 6 % PA)		$1.01
Operating costs	$3.50	
Delivery cost (20 miles)		$3.00
Fixed/Capital costs	$20.00	
Subtotal	$27.51	
Total cost per cu yd	$94.66	

Option 2 - Lithium admixture

100% dosage of lithium would be
705 lbs cement x 0.48% Na_2O equivalent x 0.55 gals = 1.9 gals 30% lithium nitrate solution

Cement	705 lbs	$ 86.00/ton	$30.32
Coarse agg	1874 lbs	$7.00/ton	$6.56
Sand	1533 lbs	$6.00/ton	$4.60
Lithium	1.9 gal	$15.00/gal	$28.50
Admixtures, etc.			$0.50
Material waste	2.5 %		$1.76
		Total	$72.24

Assume that the following are your additional costs/cu yd		
Interest on money (90-day pay, 6% PA)		$1.08
Operating costs	$3.00	
Delivery cost (20 miles)		$3.00
Fixed/Capital costs	$20.00	
Subtotal	$27.08	
Total cost per cu yd	$99.32	

Option 3 - Combination of lithium with Class F fly ash

Amount of F Ash 705 x 0.25 % = 176 lbs
Amount of cement 705 – 176 = 529 lbs
Amount of lithium
529 lbs x 0.48% Na_2O equivalent x 0.55 gals x 52% = 0.73 gal

Cement	529 lbs	$86.00/ton	$22.75
Class F Ash	176 lbs	$65.00/ton	$5.72
Coarse agg	1874 lbs	$7.00/ton	$6.56
Sand	1533 lbs	$6.00/ton	$4.60
Lithium	0.7 gal	$ 15.00/gal	$10.95
Admixtures, etc.			$0.50
Material waste	2.5 %		$1.27
		Total	$52.35

Assume that the following are your additional costs/cu yd	
Interest on money (90-day pay, 6 % PA)	$0.78
Operating costs	$3.00
Delivery cost (20 miles)	$3.00
Fixed/Capital costs	$20.00
Subtotal	$26.78
Total cost per cu yd	$79.13

From these calculations it is obvious that the combination of Class F fly ash with lithium is the most cost effective. Even though straight lithium appears a bit more expensive than nonreactive aggregates, it is still the second best option because lithium is paid separately as a line item, which is not available with the non-reactive aggregates option.

Conclusions

While going through the process for determining what the actual costs of alternatives provided in the specifications to address ASR are, an understanding of the methodology and using it to cost out a project may make the difference between winning or losing a bid. In addition, the methodology can help to insure that all costs are taken into account during the bidding process and you do not find yourself in the situation of having bid too low and risk losing money on a project. The Euclid Chemical Company and FMC Corporation have collaborated to develop a spreadsheet that allows comparison of the alternatives and develop accurate costs for all the alternatives avoiding a lot of the paperwork. While this spreadsheet is in a Beta version, representatives of either company can access the worksheet to help you implement the methodology. ■

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The views and opinions expressed in this article are those of the author and do not necessarily reflect the views and opinions of the National Ready Mixed Concrete Association.

[1]This evaluation and specification requirement is primarily in the FAA P-501 specification and is in response to aggressive deterioration, attributed to ASR, as a result of the use of newer pre-snow deicing chemicals, such as potassium acetate. The evaluation of the cause of deterioration and mitigative testing procedures is currently being researched.