Evaluation of PCC Long-Term Durability Using Intermediate Sized Gravels to Optimize Mix Gradations

Final Report
for
MLR-00-03

April 2010

Highway Division

Iowa Department Of Transportation

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April 2010

TECHNICAL REPORT TITLE PAGE

1. REPORT NO.

MLR-00-03

2. REPORT DATE

April 2010

3. TITLE AND SUBTITLE

Evaluation of PCC Long-Term Durability
Using Intermediate Sized Gravels
to Optimize Mix Gradations

4. TYPE OF REPORT & PERIOD COVERED

Final Report, August 2000 to April 2010

5. AUTHOR(S)

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7. ACKNOWLEDGMENT OF COOPERATING ORGANIZATIONS/INDIVIDUALS

8. ABSTRACT

With the implementation of the 2000 Q-MC specification, an incentive is provided to produce an optimized gradation to improve placement characteristics. Also, specifications for slip-formed barrier rail have changed to require an optimized gradation. Generally, these optimized gradations have been achieved by blending an intermediate aggregate with the coarse and fine aggregate. The demand for this intermediate aggregate has been satisfied by using crushed limestone chips developed from the crushing of the parent concrete stone. The availability, cost, and physical limitations of crushed limestone chips can be a concern.

A viable option in addressing these concerns is the use of gravel as the intermediate aggregate. Unfortunately, gravels of Class 3I durability are limited to a small geographic area in Mississippi river sands north of the Rock River. Class 3 or Class 2 durability gravels are more widely available across the state. The durability classification of gravels is based on the amount and quality of the carbonate fraction of the material. At present, no service histories or research exists to assess the impact of using Class 3 or 2 durability gravels would have on the long-term durability of Portland cement concrete (PCC) pavement requiring Class 3I aggregate.

9. KEY WORDS

optimized gradation, Shilstone gradation,
Portland cement concrete,
intermediate aggregate,
pea gravel

10. NO. OF PAGES

20

DISCLAIMER

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Introduction and Objective

With the implementation of the 2000 Q-MC specification, an incentive is provided to produce an optimized gradation to improve placement characteristics. Also, specifications for slip-formed barrier rail have changed to require an optimized gradation. Generally, these optimized gradations have been achieved by blending an intermediate aggregate with the coarse and fine aggregate. The demand for this intermediate aggregate has been satisfied by using crushed limestone chips developed from the crushing of the parent concrete stone. The availability, cost, and physical limitations of crushed limestone chips can be a concern.

A viable option in addressing these concerns is the use of gravel as the intermediate aggregate. Unfortunately, gravels of Class 3I durability are limited to a small geographic area in Mississippi river sands north of the Rock River. Class 3 or Class 2 durability gravels are more widely available across the state. The durability classification of gravels is based on the amount and quality of the carbonate fraction of the material. At present, no service histories or research exists to assess the impact of using Class 3 or 2 durability gravels would have on the long-term durability of Portland cement concrete (PCC) pavement requiring Class 3I aggregate.

Materials and Mix Design

The mix design was developed in accordance with SS-01034 Quality Management Concrete. The mix design utilized well graded aggregates following the Shilstone[1] principles. The materials used are shown in Table 1.

Table 1 – Material Sources

Material	Source	Specific Gravity
Cement	Holcim Mason City I/II	3.14
Fly Ash	Ottumwa Class C	2.61
Water w/c = 0.40	Ames tap	1.00
Fine Aggregate	Cordova, IL AIL520	2.67
Coarse Aggregate	Ft. Dodge A94002	2.66
Intermediate Aggregate	various	2.55
Air Entraining Admixture	WR Grace Daravair 1400	-
Water Reducing Admixture	WR Grace WRDA-82	-

Each mix had a target air content of 7 percent and target water to cementitious (w/cm) ratio of 0.40. The average production gradations for each pea-gravel source and the crushed limestone chips were compiled from producer records. Optimized gradation designs for each source were developed using the Shilstone technique to target an approximate coarseness factor of 60 percent and workability factor of 32 percent. The optimum percentage for each intermediate source was determined. The maximum percentage of intermediate aggregate used to achieve an optimized gradation for an individual source was used as the intermediate aggregate percentage for all mixes with an increase of 5 percent. The relative percent of aggregates used for each mix was 43 percent coarse, 19 percent intermediate, and 38 percent fine aggregate.

The coarse aggregate used is a high quality pure calcium carbonate source. In the investigation, the high quality limestone chip was used as the control to compare with eight pea gravel sources as the intermediate aggregate. The durability classification of gravels is based on the amount and quality of the carbonate fraction of the material. The sources of intermediate aggregate used, including the percentage of carbonate fraction, are shown in Table 2.

Table 2 - Intermediate Aggregate Sources

Source	A-Number	Durability Class	District / County	% Carbonate
Rockford	A34502	2	2/Floyd	47
Ames South	A85510	2	1/Story	54
Army Post Road	A77520	2	1/Polk	26
Harlan	A83504	3	4/Shelby	8
Woodbine-McCann	A43512	3	4/Harrison	15
Anthon	A97522	3	3/Woodbury	30
Bellevue	A49526	3I	6/Jackson	0
Turner	A49516	3I	6/Jackson	0
Fort Dodge limestone	A94002	3I	1/Webster	100

Test Procedure

Two mixes were weighed, batched, and mixed according to ASSHTO T126 for each source. A 0.9 cubic foot batch was sufficient quantity to allow for air and slump tests as well as the fabrication of 6 durability beams. A total of 108 durability beams were tested.

One mix used washed intermediate aggregate while the second mix used salt soaked intermediate aggregate. Salt soaked aggregates were prepared by heating the aggregate to 230 °F for 12 hours. Next, 1000 grams of sodium chloride (NaCl) is dissolved in hot tap water. This salt solution is then poured over the hot aggregate until the aggregate is entirely immersed. The aggregate is soaked for 24 hours in the salt solution. Finally, the aggregate is removed from the salt solution and rinsed. The rinsed aggregate is dried to SSD condition for incorporation into the mix.

All beams were fabricated and tested according to ASTM 666 procedure B. In order to compare to previous freeze thaw durability testing, 89 days of moist room curing was conducted. Testing was terminated when either 300 freeze-thaw cycles were completed or until a relative dynamic modulus of elasticity of 60 percent was reached. After freeze thaw durability testing was terminated the beams were removed from the freezer and stored in the freezer room.

After the completion of durability testing, a sample was obtained from each set of beams. The samples were polished using a lapping wheel. The sections were examined using an optical microscope and SEM. Qualitative observations were made to determine if the intermediate aggregate exhibited any potential for increased deterioration.

ASTM C 666 Results

The results of the ASTM C 666 method B freeze thaw durability testing are found in Table 1. Graphical representation of the relative durability factor (DF) and percent growth are found in Figures 1 and 2. Individual beam test data are found in the Appendix.

Table 3 – ASTM C 666 Method B data

Source	% Expansion		Durability Factor	
	No-salt	Salt	No-salt	Salt
Rockford	0.0031	0.0039	90	89
Ames South	0.0028	0.0048	91	89
Army Post	0.0020	0.0025	92	92
Harlan	0.0014	0.0020	94	93
Woodbine-McCann	0.0023	0.0040	92	90
Anthon	0.0039	0.0060	91	90
Bellevue	0.0041	0.0039	91	93
Turner	0.0040	0.0043	90	88
Fort Dodge	0.0035	0.0033	90	89

Figure 1 – Average ASTM C 666 B durability factors salt and non-salt by source

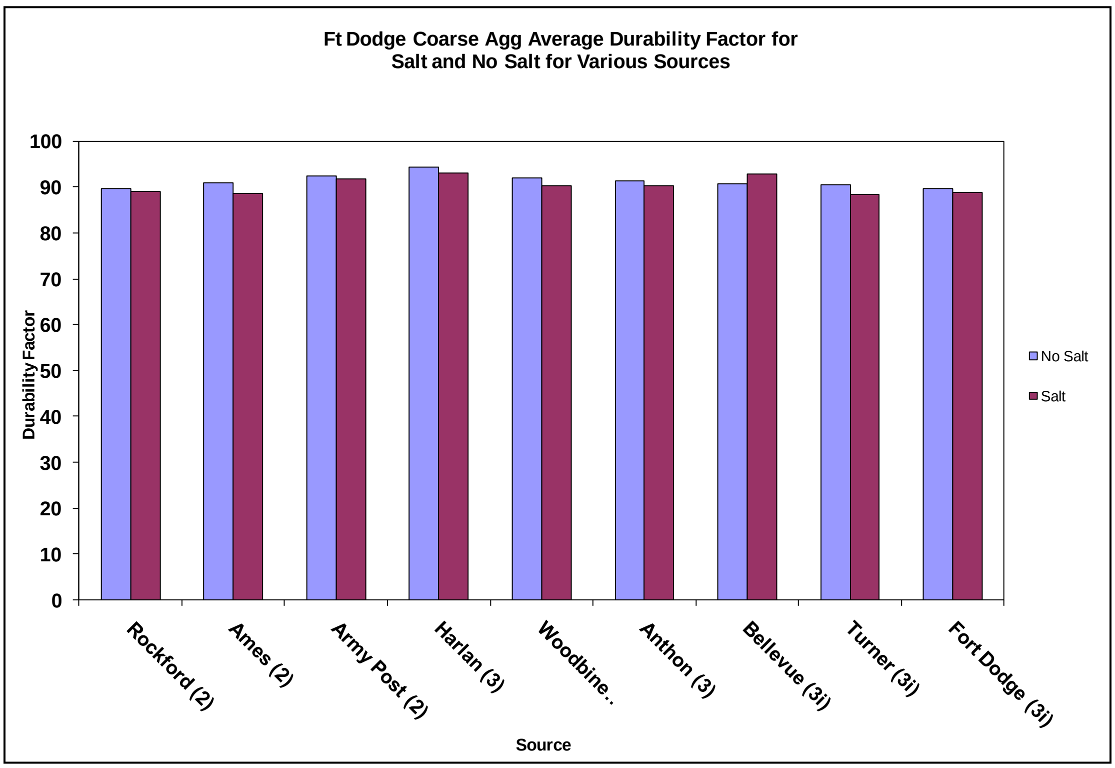
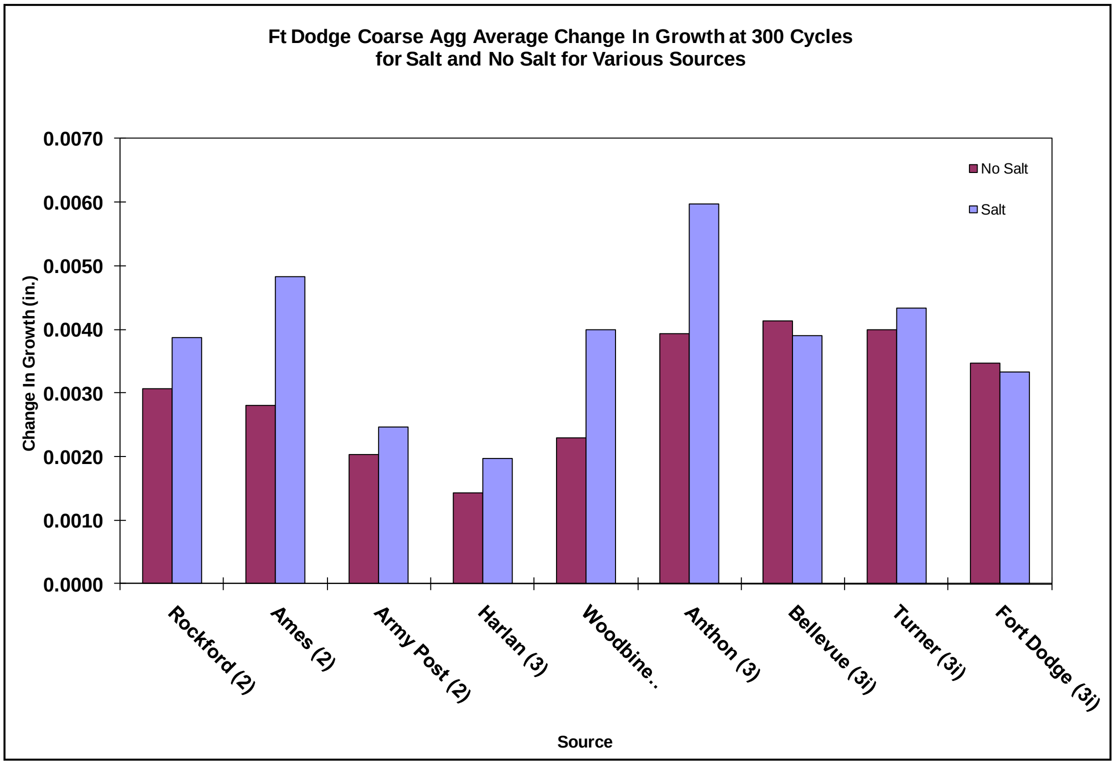


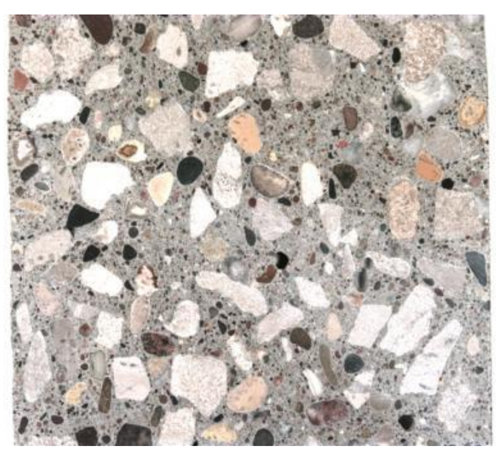
Figure 2 – Average expansion for salt and non-salt by source



Petrographic analysis

Since little difference was noted between the freeze thaw durability beams, sections from a sampling of the salt soaked aggregate beams were examined for petrographic analysis. Two Class 2 sources, two Class 3 source, and one Class 3I source examined to determine if any of the intermediate aggregates showed signs of distress. One sample was obtained from the middle of the beam and one near the edge of the beam. Polished sections were obtained from the beams and examined under an optical microscope. The optical images overall view are shown in Figures 3-12.

Figure 3 – Rockford optical images (no salt) - middle (l), edge (r)



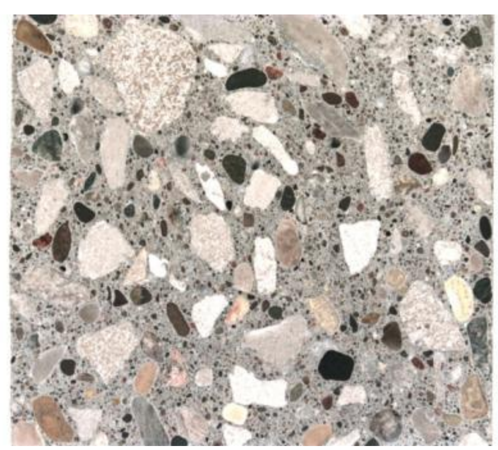


Figure 4 – Rockford optical images (salt) - middle (l), edge (r)

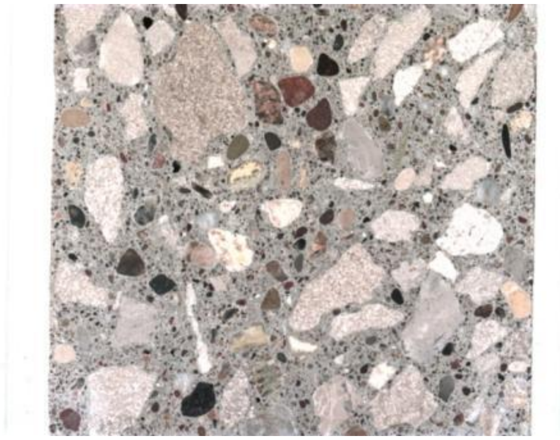
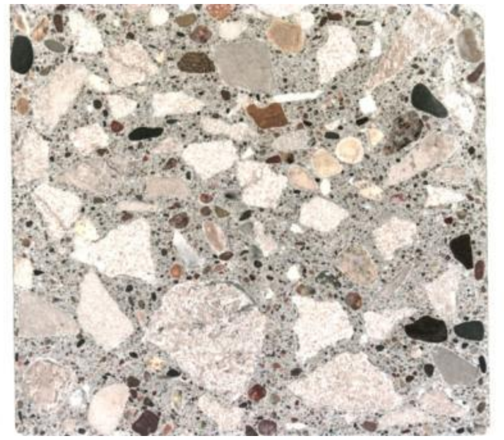



Figure 5 – Army Post Road optical images (no salt) - middle (l), edge (r)

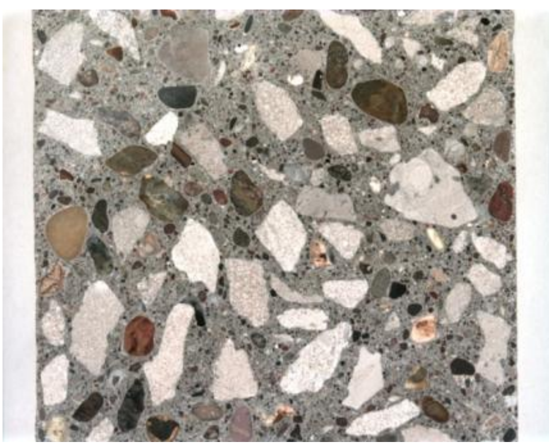
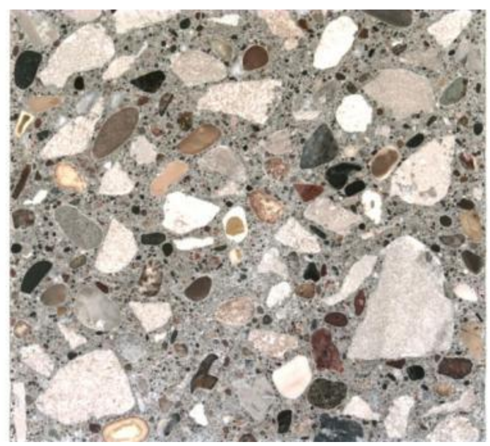



Figure 6 - Army Post Road optical images (salt) - middle (l), edge (r)

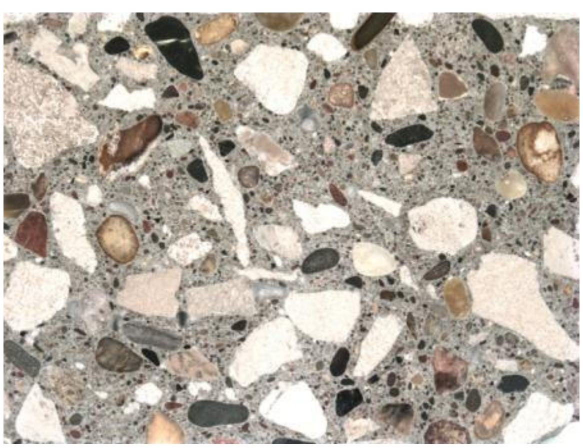



Figure 7 - Anthon optical images (salt) - middle (l), edge (r)

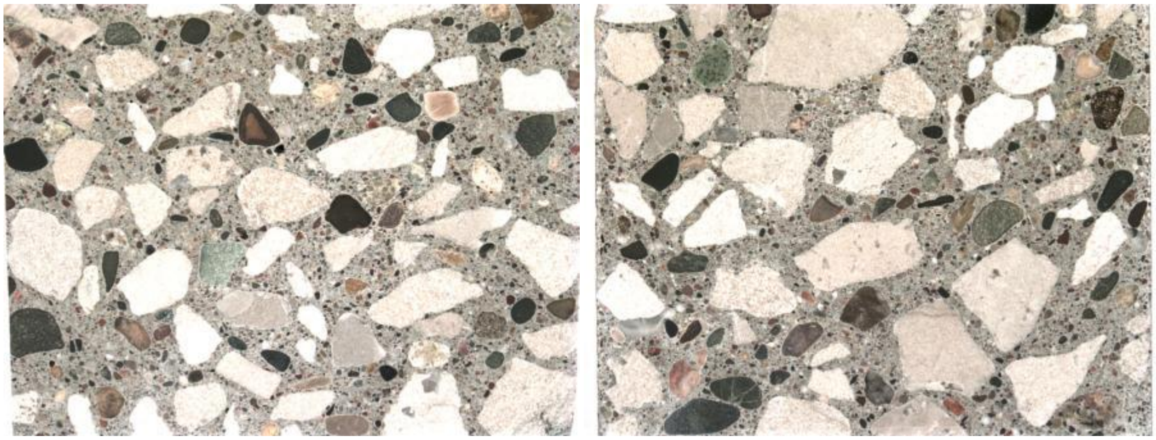


Figure 8 – Woodbine optical images (salt) - middle (l), edge (r)

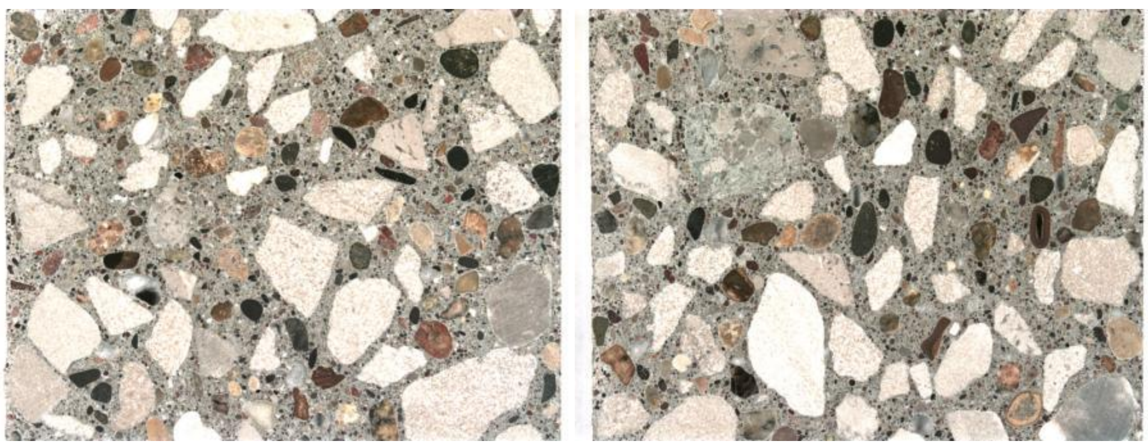


Figure 9 - Bellevue optical images (no salt) - middle (l), edge (r)

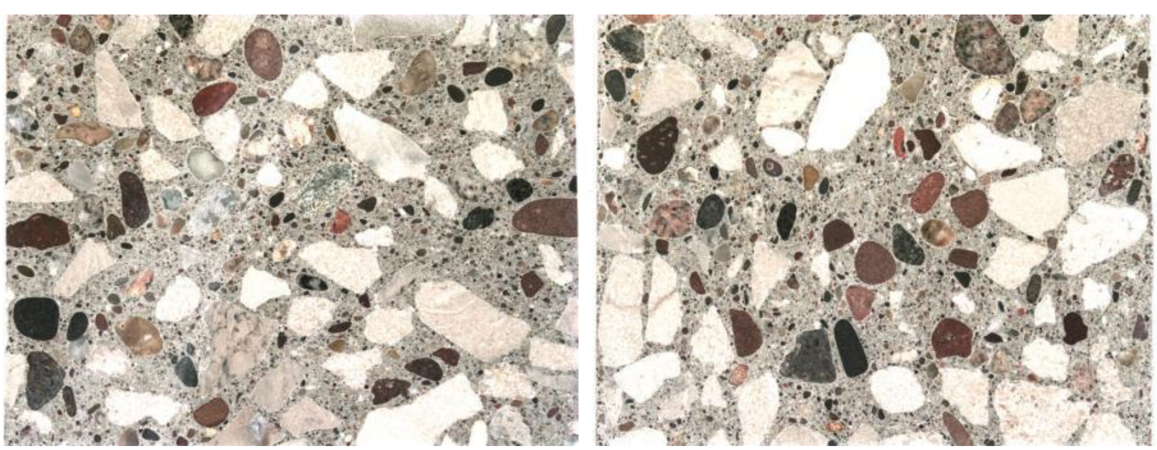
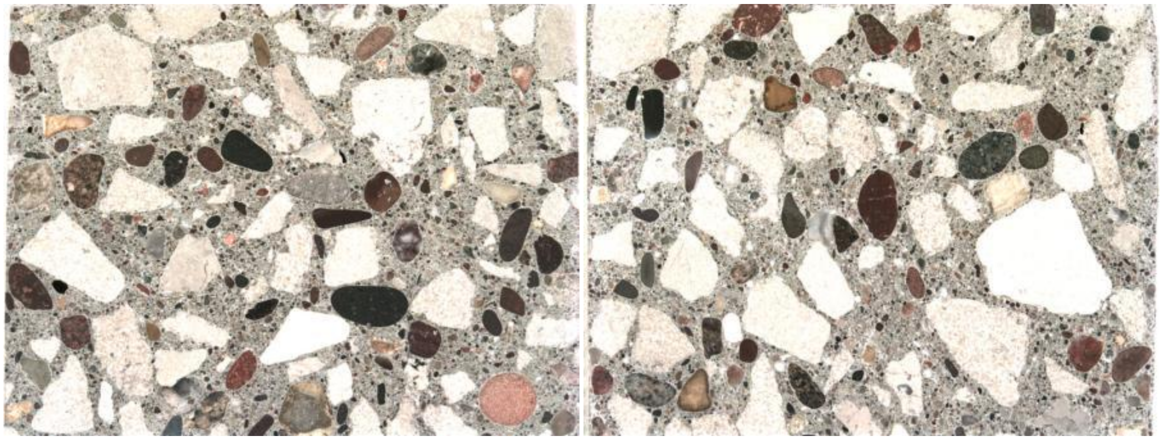


Figure 10 - Bellevue optical images (salt) - middle (l), edge (r)



Little deterioration was noted in any of the samples investigated. Salt was concentrated in a rim around a few aggregate particles, but no deterioration was noted. Pyrite, found in some samples, also exhibited little signs of deterioration.

Figure 11 – Salt concentrated around aggregate in Woodbine sample

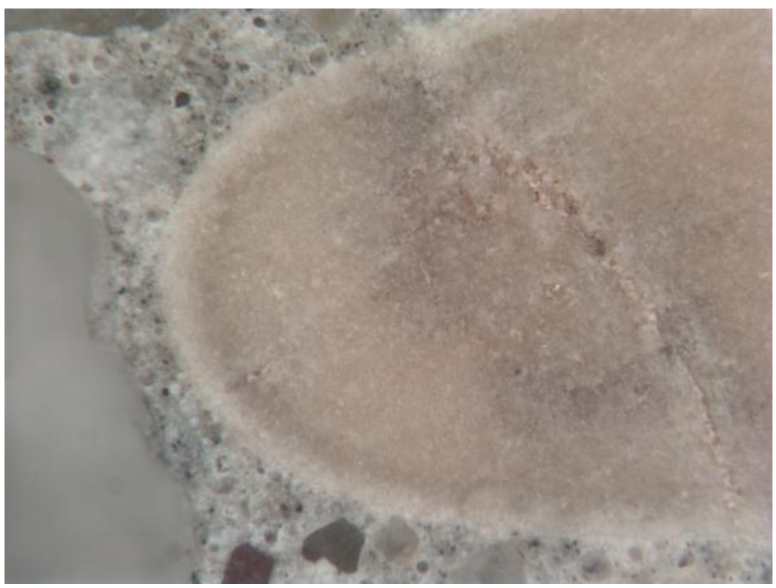
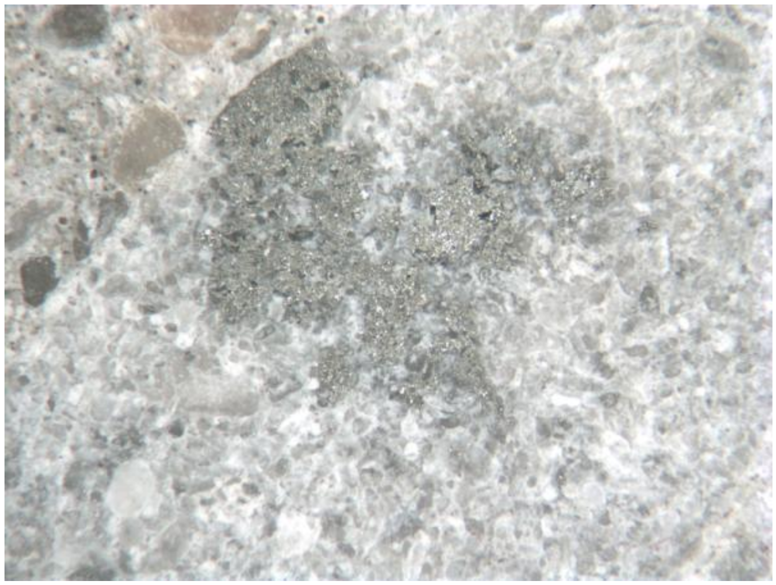


Figure 12 – Pyrite in Bellevue salt sample



Discussion

Based on ASTM C 666 freeze thaw durability testing Method B, it appears that addition of pea gravel at 19 percent relative of total aggregate, does not drastically affect the durability rating, salt or non salt, as compared to the control, regardless of the gravel durability classification. The percent growth increases slightly in the salt soak specimens, especially in those sources with higher amounts of carbonate fraction.

Typically, approximately 10 to 12 percent pea gravel is needed to achieve a well graded Shilstone aggregate combination using a coarse aggregate meeting Gradation No. 3 and a sand meeting Gradation No. 1. This research was conducted at a much higher percentage that would typically be required. Since 19 percent pea gravel had relatively minimal influence on durability rating, using a lower percentage of pea gravel should have even lesser affect on durability.

Conclusions and Recommendations

Based on the findings of this report, the following recommendations:

- When Class 3I aggregate is required, utilize pea gravels from Class 2 or Class 3 sources as an intermediate aggregate, limited to 15% of the total aggregate.

- Develop specifications for pea gravel to limit amounts of deleterious materials.

Acknowledgement

The author would like to thank the following people for their help in this research:

Paul Hockett for procuring all the aggregate samples, Mike Coles, Leroy Lutjen, and Ken Kennedy in the Cement and Concrete section for casting and testing the specimens, and Bob Dawson, Geologist, for the petrography work.

References

1. Shilstone, J. Sr., ”Concrete Mixture Optimization”, Concrete International, June 1990

Appendix

Figure 13 – Aggregate Gradations

Coarse

Source	State ID	Specific Gravity SSD	3"	2 1/2"	2"	1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Fort Dodge	A94002	2.66	100.0	100.0	100.0	100.0	100.0	75.0	52.0	15.0	2.5	1.0	0.9	0.8	0.7	0.6	0.5
													0.0	0.0	0.0	0.0	

Intermediate

Source	State ID	Specific Gravity SSD	3"	2 1/2"	2"	1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Army Post	A77520	2.65	100.0	100.0	100.0	100.0	100.0	100.0	100.0	80.0	5.0	0.5	0.4	0.4	0.3	0.3	0.2
Bellevue	A49526	DWU	100.0	100.0	100.0	100.0	100.0	100.0	100.0	90.0	3.4	0.6	0.5	0.4	0.3	0.2	0.1
Turner	A49516	2.63	100.0	100.0	100.0	100.0	100.0	100.0	99.0	63.0	1.0	0.6	0.5	0.5	0.4	0.4	0.3
Ames South	A85510	2.66	100.0	100.0	100.0	100.0	100.0	100.0	100.0	88.0	1.3	0.2	0.2	0.2	0.1	0.1	0.1
Harlan	A83504	2.67	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97.0	40.0	2.9	2.4	1.8	1.3	0.7	0.2
Rockford	A34502	2.68	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.0	12.8	4.5	3.8	3.0	2.3	1.5	0.8
Woodbine McChan	A43512	DWU	100.0	100.0	100.0	100.0	100.0	100.0	100.0	96.0	19.0	5.7	4.6	3.5	2.4	1.3	0.2
Anthon	A97522	2.72											0.0	0.0	0.0	0.0	
Fort Dodge	A94002	2.66	100.0	100.0	100.0	100.0	100.0	100.0	99.0	74.0	7.6	1.7	1.5	1.2	1.0	0.7	0.5
Average			100.0	100.0	100.0	100.0	100.0	100.0	100.0	86.0	11.0	2.1	1.7	1.4	1.0	0.7	0.3

Fine

Source	State ID	Specific Gravity SSD	3"	2 1/2"	2"	1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Cordova	AIL520	DWU	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.0	87.0	73.0	38.0	6.0	0.9	0.4
			100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0							
			100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0							

Figure 14 – Mix Proportions

GENERAL INFORMATION					
PROJECT:	Intermediate Agg.				
PROJECT TITLE:	#REF!				
MIX TYPE:	QM-C				
MIX NUMBER:	fortdodge				
DATE:	09/21/00				
MATERIALS	*Source*	*Type/Class*	*SPG*	*Percent*	*Percent*
CEMENT:	Holnam	I/II	3.14		
FLY ASH:	Ottumwa	C	2.61	20.00	
MINERAL ADMIXTURE:				0.00	
SILICA FUME SLURRY:				0.00	
FINE AGGREGATE:	AIL520		2.67	38.00	
COARSE AGGREGATE:	A94002		2.66	43.03	69.40
INTERMEDIATE AGGREGATE:	A94002		2.66	18.97	30.60
AIR ENTRAINING AGENT:	DARAVAIR 1400				
RETARDER:					
WATER REDUCER:	WRDA-82				
SUPER WATER REDUCER:					
ACCELERATOR:					
DESIGN W/C(+FLY ASH):	0.40				
DESIGN SLUMP:	1.8				
DESIGN AIR CONTENT:	7.0				

QUANTITIES (absolute volume method in SSD condition)

	Volume ft3 Batch Size 1.0 yd3	Volume ft3 Batch Size 1.0 ft3						Weight lbs Batch Size 1.0 ft3	Weight lbs Batch Size 1.0 yd3	Weight lbs Lab Batch Size 0.9
CEMENT:	2.2853	0.0846	X	3.14	X	62.4	=	16.6	448	14.9
FLY ASH:	0.6873	0.0255	X	2.61	X	62.4	=	4.1	112	3.7
MINERAL ADMIXTURE:	0.0000	0.0000						0.0	0	0
SILICA FUME SLURRY:	0.0000	0.0000						0.0	0	0
WATER:	3.5879	0.1329	X	1.00	X	62.4	=	8.3	224	7.5
FINE AGGREGATE:	7.0488	0.2611	X	2.67	X	62.4	=	43.5	1174	39.1
COARSE AGGREGATE:	7.9815	0.2956	X	2.66	X	62.4	=	49.1	1325	44.2
INTERMEDIATE AGGREGATE:	3.5192	0.1303	X	2.66	X	62.4	=	21.6	584	19.5
AIR:	1.8900	0.0700	X	0.00	X	62.4	=	0.0	0	0.0
Summation	**27.0000**	**1.0000**						**143.2**	**3867**	**128.9**
Paste Content	**24.3**									
Mortar Content (abs vol)	**57.4**									
Mortar Content (% pass)	**54.6**									

CHEMICAL ADMIXTURES

	Rate oz/100 lbs cementitious							Rate ml Batch Size 1.0 ft3	Rate ml Batch Size 1.0 yd3	Rate ml Lab Batch Size 0.9
AIR ENTRAINING AGENT:	0.8	20.73	X	0.008	X	29.57	=	4.9	132.4	4.4
RETARDER:										
WATER REDUCER:	3.5	20.73	X	0.035	X	29.57	=	21.5	579.3	19.3
SUPER WATER REDUCER:										
ACCELERATOR:										

Figure 15 – Coarseness and Workability Factors

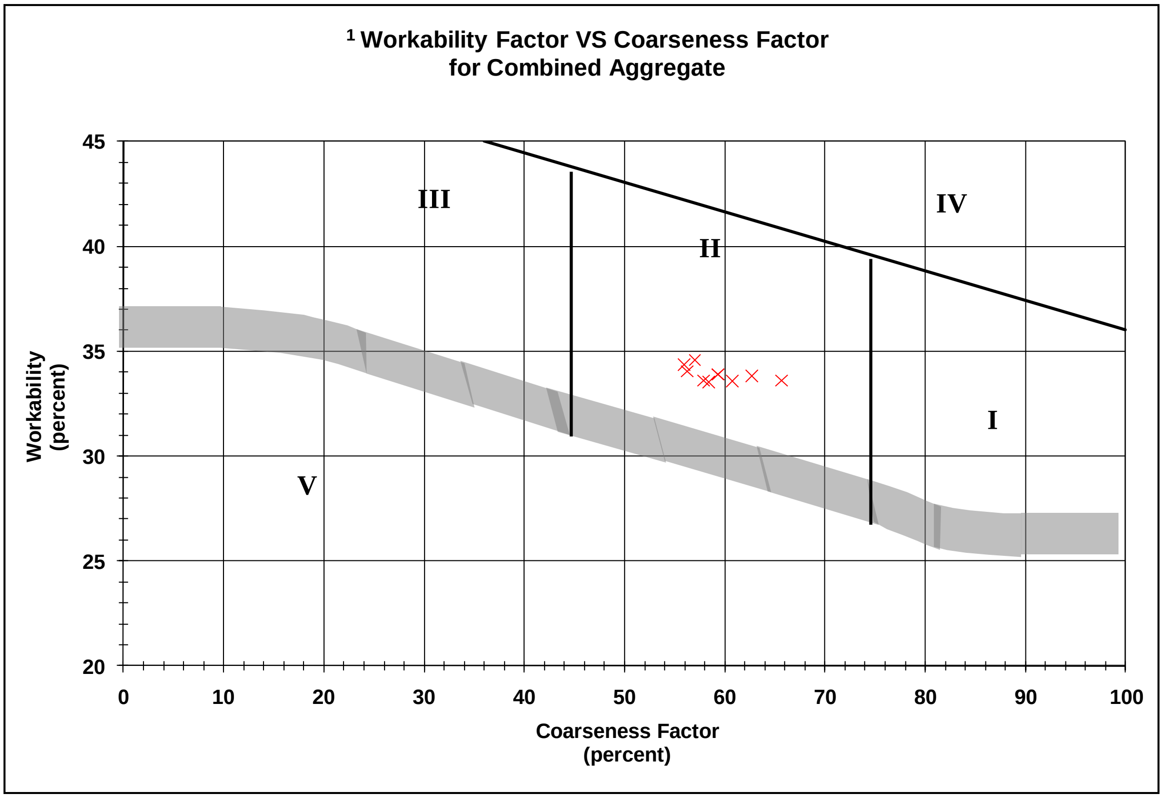


Figure 16 – Combined Percent Passing Gradations 0.45 Power Curve

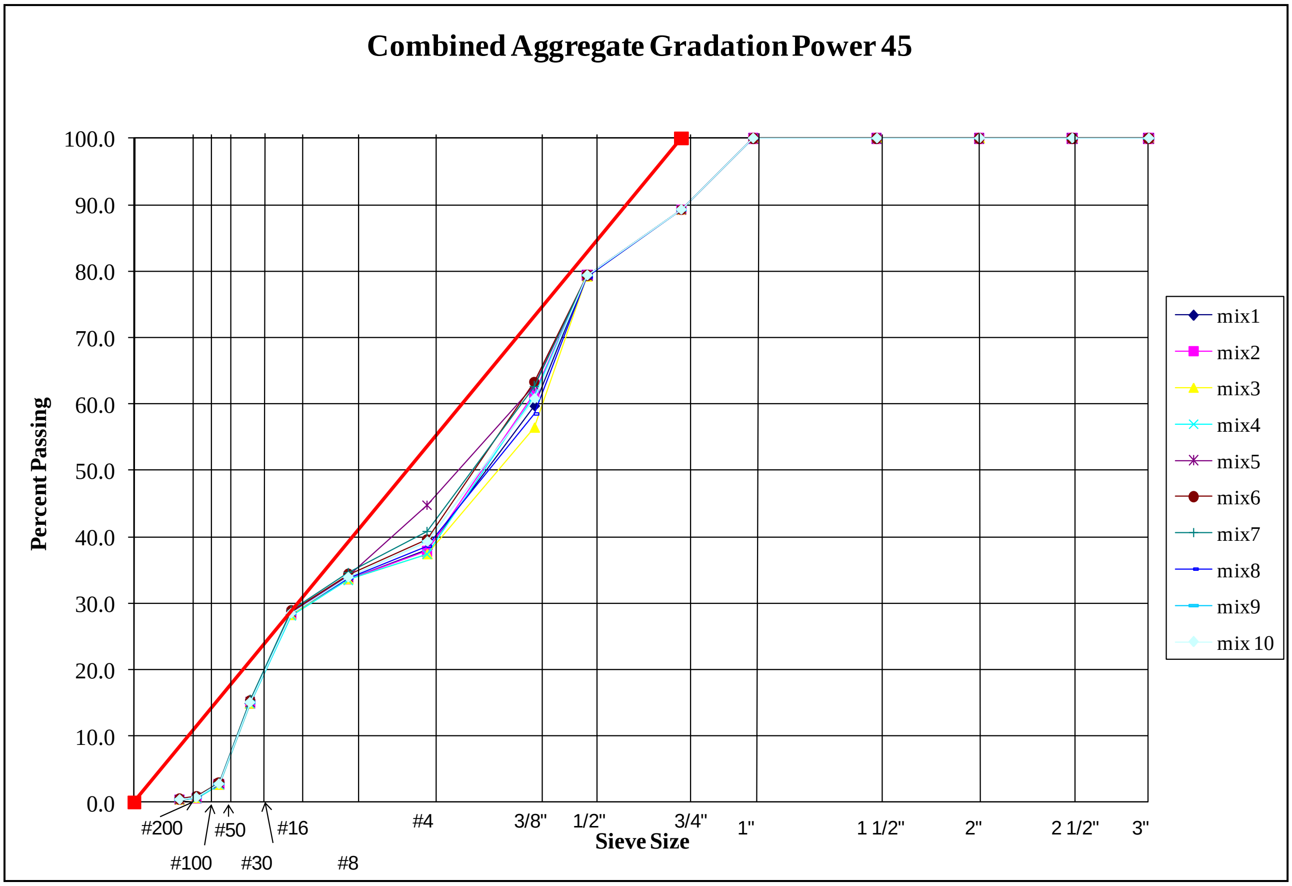


Figure 17 – ASTM C 666 B Individual Beam Test Results

	Rockford		Ames		Army Post		Harlan		Woodbine McCar		Anthon		Bellevue		Turner		Fort Dodge	
	No Salt	Salt	No Salt	Salt	No Salt	Salt	No Salt	Salt	No Salt	Salt	No Salt	Salt	No Salt	Salt	No Salt	Salt	No Salt	Salt
Beam 1	0.0034	0.0047	0.0021	0.0047	0.0017	0.0029	0.0013	0.0017	0.0027	0.0042	0.0027	0.0065	0.0046	0.0032	0.0048	0.0031	0.0032	0.0038
Beam 2	0.0036	0.0029	0.0033	0.0048	0.0023	0.0027	0.0018	0.0020	0.0016	0.0038	0.0050	0.0062	0.0039	0.0044	0.0040	0.0033	0.0033	0.0031
Beam 3	0.0022	0.0040	0.0030	0.0050	0.0021	0.0018	0.0012	0.0022	0.0026	0.0040	0.0041	0.0052	0.0039	0.0041	0.0032	0.0066	0.0039	0.0031
Avg.	0.0031	0.0039	0.0028	0.0048	0.0020	0.0025	0.0014	0.0020	0.0023	0.0040	0.0039	0.0060	0.0041	0.0039	0.0040	0.0043	0.0035	0.0033
	No Salt	Salt	No Salt	Salt	No Salt	Salt	No Salt	Salt	No Salt	Salt	No Salt	Salt	No Salt	Salt	No Salt	Salt	No Salt	Salt
Beam 1	89	86	89	90	92	91	94	93	90	90	91	90	92	91	87	87	87	85
Beam 2	88	92	92	86	93	91	93	93	92	91	91	89	91	93	91	90	91	89
Beam 3	92	89	91	90	92	92	96	92	95	90	91	91	88	93	92	87	90	92
Avg.	90	89	91	89	92	92	94	93	92	90	91	90	91	93	90	88	90	89

Figure 18 – Rockford freeze thaw beams Rockford (no salt)

Figure 19 – Rockford freeze thaw beams (salt)

Figure 20 – Ames South freeze thaw beams (no salt)

Figure 21 – Ames South freeze thaw beams (salt)

Figure 22 – Army Post Road freeze thaw beams (no salt)

Figure 23 – Army Post Road freeze thaw beams (salt)

Figure 24 – Harlan freeze thaw beams (no salt)

Figure 25 – Harlan freeze thaw beams (salt)

Figure 26 – Woodbine-McCann freeze thaw beams (no salt)

Figure 27 – Woodbine-McCann freeze thaw beams (salt)

Figure 28 – Anthon freeze thaw beams (no salt)

Figure 29 – Anthon freeze thaw beams (salt)

Figure 30 – Bellevue freeze thaw beams (no salt)

Figure 31 – Bellevue freeze thaw beams (salt)

Figure 32 – Turner freeze thaw beams (no salt)

Figure 33 – Turner freeze thaw beams (salt)