Evaluations of Nano-Sized Hydrated Lime on the Moisture Susceptibility of Hot Mix Asphalt Mixtures

Article *in* Applied Mechanics and Materials · May 2012

DOI: 10.4028/www.scientific.net/AMM.174-177.82

4 authors, including:

Junan Shen
Georgia Southern University

Zhaoxing Xie
Auburn University

Feipeng Xiao

Applied Mechanics and Materials Vols. 174-177 (2012) pp 82-90
Online available since 2012/May/14 at www.scientific.net

doi:10.4028/www.scientific.net/AMM.174-177.82

Evaluations of Nano-sized Hydrated Lime on the Moisture Susceptibility of Hot Mix Asphalt Mixtures

Junan Shen[1], Zhaoxing Xie[2], Feipeng Xiao[3], Wenzhong Fan[4]

[1,2,3,] Suzhou University of Science and Technology, China

[1,2]Georgia Southern University, USA

[4]Suzhou Traffic Engineering Group Cooperation, Suzhou, China

[1]shenjunan@hotmail.com [2]xzx9898@163.com [3] fpxiao@gmail.com

[4] fanwenzhong2000@sohu.com

Keywords: Nano lime; Anti-stripping additive; Indirect tensile strength; Flow; Toughness

Abstract: The objective of this study was to evaluate the effect of nano-sized hydrated lime on the moisture susceptibility of the hot mix asphalt (HMA) mixtures in terms of three methodologies to introduce into the mixtures. The experimental design for this study included the utilizations of one binder source (PG 64-22), three aggregate sources and three different methods introducing the lime. A total of 12 types of HMA mixtures and 72 specimens were fabricated and tested in this study. The performed properties include indirect tensile strength (ITS), tensile strength ratio (TSR), flow, and toughness. The results indicated that the nano-sized lime exhibits better moisture resistance. Introducing process of the nano-sized lime will produce difference in moisture susceptibility.

INTRODUCTION

A typical situation of hot asphalt mix (HAM) mixtures is the gradual loss of strength over the years, which causes many surface manifestations like rutting, corrugations, shoving, raveling, cracking, etc [1-3]. This phenomenon of breaking of the bond between the aggregate and the binder is known as stripping. Some researchers identified six contributing mechanisms that might produce moisture damage: detachment, displacement, spontaneous emulsification, pore pressure-induced damage, hydraulic scour, and the effects of the environment on the aggregate-asphalt system [4]. To prevent moisture susceptibility, proper mix design is essential. Of the many ways to prevent stripping in a pavement, the use of anti-stripping agents (ASAs) is the most common [5-6]. One of the most commonly used ASAs in the United States is hydrated lime. Shen et al. [7] found that the effect of a super fine hydrated lime with particle average size of 660 nm on the anti-stripping properties of HMA by adding 1% of the sub nano-sized hydrated lime was affirmative. The indirect tension strength (ITS) values of the HMA containing nano hydrated lime increased roughly 10%, compared with those with regular hydrated lime [7]. Thus, a proper study of introducing methodology for nano-sized lime into the HMA should be done by systematically testing the mix for moisture susceptibility using tests like ITS in the laboratory.

Moisture damage is usually not limited to one mechanism rather than the result of a combination of many processes. From a chemical standpoint, the literature is clear that though neither asphalt nor aggregate has a net charge, components of both have nonuniform charge distributions, and both behave as if they have charges that attract the opposite charge of the other materials. The blending process of hydrated lime with aggregate or with asphalt binder or with water directly to produce slurry may affect the charge re-distribution and thus may affect the moisture susceptibility of the mixture. Especially, as different types of aggregates were used, the physical and chemical properties of aggregate may play an important role in determining the ITS values of mixtures [8].

The objective of this study was to evaluate the effect of nano-sized hydrated lime on the moisture susceptibility of HMA mixtures in terms of three methodologies to introduce into the mixtures, i.e., nano lime modified with asphalt binder, nano lime mixed with water, and nano lime blended with aggregate directly. Experiments were carried out to use the following testing procedures such as indirect tensile strength (ITS), tensile strength ratio (TSR), flow, and toughness.

EXPERIMENTAL MATERIALS AND TEST PROCEDURE

Materials

The experimental design detailed in this study included the use of one binder grade (PG 64-22), and three aggregate sources (designated as A, B, and C). The engineering properties of coarse and fine aggregate sources are shown in Table 1. Aggregate A (schist) is a metamorphic rock while aggregate source C (granite) is composed predominantly of quartz and potassium feldspar. Aggregate B has larger percentage values of Al_2O_3 and SiO_2 than aggregate A. Coarse aggregate A has the highest LA abrasion loss percentage and absorption while aggregate C has the lowest.

Table 1 Physical properties of aggregates

Coarse Aggregate	LA Abrasion Loss (%)	Absorption (%)	Specific Gravity (BLK)	Soundness % Loss at 5 Cycles			Sand Equivalent	Hardness
				11/2 to 3/4	3/4 to 3/8	3/8 to No.4		
A	49	1.05	2.700	0.2	0.1	0.1	-	5
B	32	0.75	2.770	0.4	0.6	0.9	38	5
C	28	0.50	2.660	1.1	1.7	4.1	53	6

Note: A: aggregate A, B, aggregate B, C: aggregate C, BLK: bulk specific gravity

The LA abrasion machine produced super fine nano lime powder was dispersed in acetone by sonicating for 20 minutes. The resulting suspension was dropped onto a clean Si substrate and dried under air. The prepared samples were coated with a very thin layer of Au to increase the conductivity to get clear SEM images of the sample morphology. Hydrated lime is commonly used for anti-stripping of the mixture by being added to the aggregate (1% by weight of dry aggregate).

In this study, three different methodologies were used to produce nano lime mixtures. One regular method was to blend nano lime with the dried aggregate and then mixed with 5% water (by weight of dry aggregate) to make nano lime coat the aggregate completely. It was referred as DNL, second method was to add 1% nano lime to 5% water to generate the slurry, which was mixed with the aggregate. It was denoted as SNL. These aggregates produced from these two approaches were oven dried before mixing. Third method is to add nano lime into asphalt binder and blend for 30 minutes at a speed of 700 rpm and a temperature of 163°C. The modified nano lime (MNL) binder was used to mix with the aggregate in the laboratory.

Thermal-Assisted Field Emission SEM provided by Georgia Institute of Technology was used to take images of nano lime. It is a state-of-the–art equipment that can yield 1 nm resolution at 20 kv and 3 nm at 1kv with operating voltage ranges from 200v to 30kv. The images of these nano lime are shown in Figure 1.

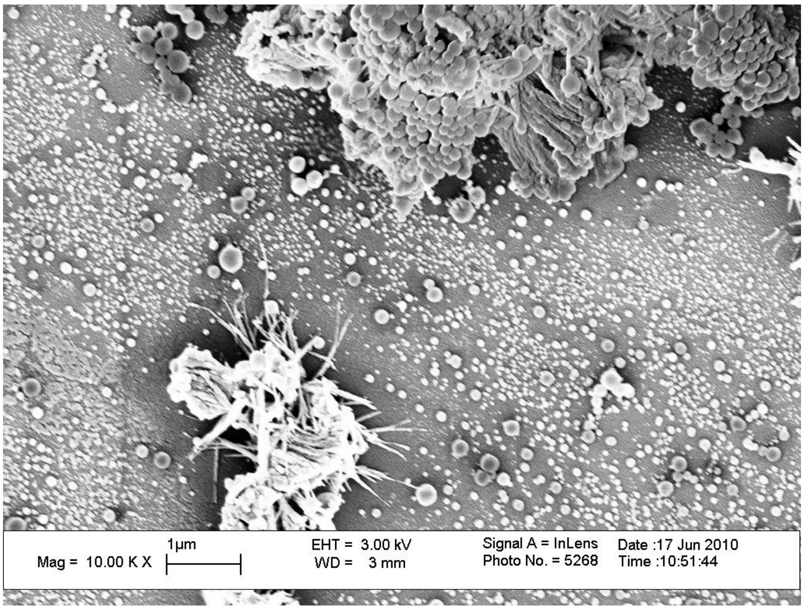


Figure 1. SME of Nano-sized Hydrated Lime

Mix Design, Sample fabrication and testing

The mix design included the aggregates used for a 12.5 mm mixture that satisfied the specifications set forth by the South Carolina Department of Transportation (SCDOT). The design aggregate gradations for each aggregate source were the same when using different methods. The gradations of three aggregates between low and up ranges defined by SCDOT are presented in Table 2. Obviously, the passing percentages of these three gradations are generally similar, and thus the effects of aggregate on the mixtures can be neglected in this study.

Table 2 Passing percentages of aggregates

Sieve Size (mm)	**Low range**	Agg. A	Agg. B	Agg. C	**Up range**
19	**98**	99.0	99.6	99.7	**100**
12.5	**90**	93.9	93.7	94.3	**100**
9.5	**74**	88.6	83.7	84.7	**90**
4.75	**46**	48.8	49.3	50.9	**62**
2.36	**25**	29.6	39.0	32.5	**41**
0.6	**9**	18.3	17.8	17.3	**21**
0.15	**4**	6.6	8.5	8.1	**12**
0.075	**2**	3.3	5.1	5.0	**8**

Superpave mix design defines that the laboratory mixing and compaction temperatures can be determined by using a plot of viscosity versus temperature. The mixing temperatures of 152°C were employed to blend asphalt binder and aggregate. The compaction temperature of 145^{o}C was used in this study regardless of produced nano lime method and aggregate type.

In Superpave mix design, the optimum binder content (OBC) was defined as the amount of binder required to achieve 3.5-4.0% air voids in accordance with SCDOT volumetric specifications. The detailed mix designs are shown in Table 3. It can be noted that the OBC value of the mixture from aggregate A is higher than these values of mixtures from aggregates B and C. The mixture from aggregate B has the lowest OBC value of 4.8% greater than minimum value of 4.5% set forth by SCDOT. The voids in mineral aggregate (VMA) and voids filled with asphalt binder (VFA) values of all mixtures are higher than 14.5% and between 70-80%, respectively. In addition, the ratios of dust to asphalt contents of mixtures are in the range of 0.6-1.20. Therefore, all mixtures followed SCDOT Superpave mix design specifications in this study.

Table 3 Superpave mix designs of mixtures

Mix types	OBC	MSG	VMA	VFA	Dust/Asphalt ratio
A	5.90%	2.490	17.5	77.5	0.88
B	4.80%	2.634	15.2	77.3	1.05
C	5.45%	2.421	16.8	76.6	0.98

Note: A: aggregate A, B, aggregate B, C: aggregate C, OBC: optimum binder content, MSG: maximum specific gravity, VMA: Void in mineral aggregate, VFA: Voids filled with asphalt

It should be noted that overall mixtures from various aggregate sources used the same regular hydrated lime content of 1%. After the mix designs were completed, for each aggregate, these three blended nano limes were used to make six Superpave gyratory compacted specimens (150mm in diameter and 95mm in height) were prepared with 7 ± 1% air voids, and then the samples were tested at 25 °C (77 °F) to determine the ITS, flow and toughness values. Three of the samples were tested in dry condition and the other three in wet condition. The wet samples were conditioned in accordance with SC T 70, *Laboratory Determination of Moisture Susceptibility (*SCDOT Test Procedures, 2007*)*. The evaluated parameters included ITS, TSR, and toughness.

EXPERIMENTAL RESULTS AND DISCUSSIONS

To study the effects of three blended nano lime methods on the ITS, flow and toughness values of mixes, analysis of variance (ANOVA) was performed to test the null hypothesis that the sample means (ITS, flow, and toughness of each treatment) are not significantly different from each other at a 5% level of significance.

Gyration number analysis

For gyratory asphalt samples, an increase of gyration number typically reduces its air void content. SC T 70 indicates that the ITS sample should be compacted to 7 ± 1.0% air voids before testing. The gyration number required to reach the target air voids of each mixture is shown in Figure 2. It can be observed that mixtures from aggregate B have the greatest gyration number. In other words, more compaction efforts are required to achieve target air voids for mixtures from aggregate B. However, mixtures from aggregate C generally have the lowest gyration number in this study. In terms of the methodology of using nano lime in the mixture, it can be found that, compared to regular hydrated lime mixtures (CL), nano lime mixtures from aggregate A have slightly greater gyration numbers, however, nano lime mixtures from aggregate C show an opposite trend since these nano lime mixtures have lower gyration numbers. No obvious gyration number trends are found in terms of three methodologies in general. One possible reason is that the asphalt binder content and aggregate shape play a key role in affecting the compaction of mixtures

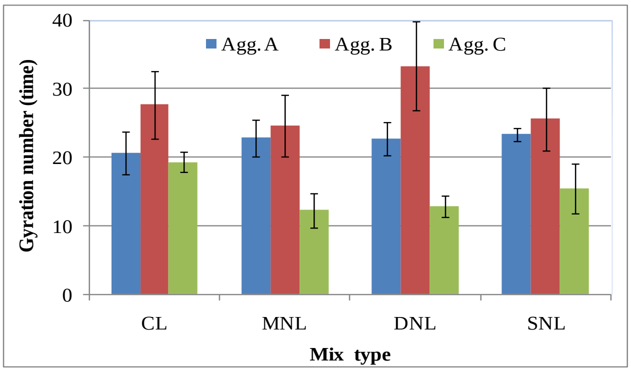
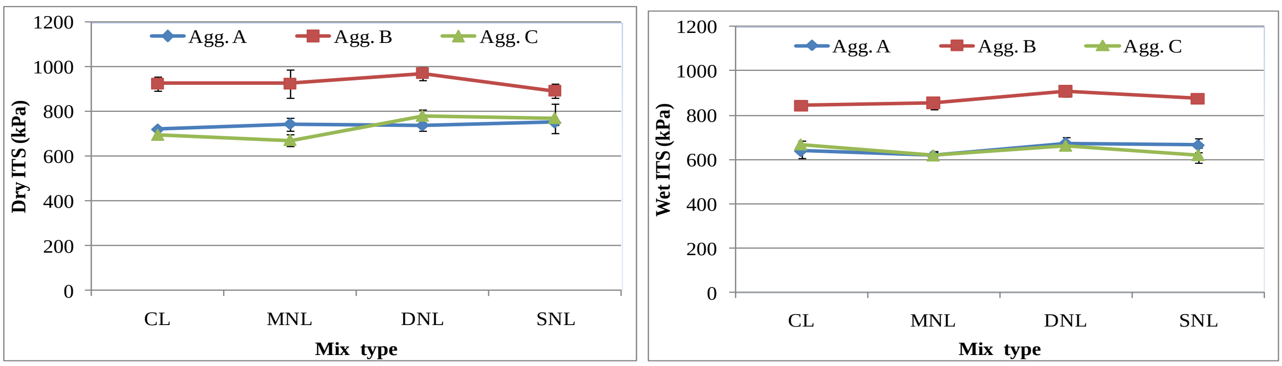


Fig. 2 Gyration numbers of mixtures

ITS analysis

The ITS test is often used to evaluate the moisture susceptibility of an asphalt mixture. A higher ITS values typically indicate that the mixture will perform well with a good resistance to moisture damage. At the same time, mixtures that are able to tolerate higher strain prior to failure are more likely to resist cracking than those unable to tolerate high strains.

The dry ITS results shown in Figure 3(a) indicate that the ITS values of specimens from aggregate B are higher while mixtures from aggregates A and C show lower ITS values regardless of the method of using nano lime. With respect to the lime type, it can be noted that mixtures with MNL generally have slightly lower or similar dry ITS values with CL mixtures but generally lower than DNL and SNL mixtures. In most cases, mixtures with DNL have relatively the highest dry ITS values. Similarly, in Figure 3(b), it can be observed that mixtures from aggregate B have the greatest wet ITS values. In addition, MNL mixtures have close or less wet ITS with CL mixtures while the wet ITS value of DNL and SNL mixtures are generally higher regardless of aggregate type. Furthermore, Figure 3(b) indicates that mixtures from aggregates A and C generally have similar wet ITS values. All mixtures have ITS values greater than 448 kPa in this study, the minimum required as per the SCDOT specifications. Statistical analysis shown in Table 4 illustrate that there is no significant difference in dry and wet ITS value amongst any mixtures made from four lime types.



(a) (b)

Fig. 3 Dry and wet ITS values

Table 4 Statistical analysis of ITS, flow, toughness values of mixtures

α = 0.05		Dry				Wet			
		CL	MNL	DNL	SNL	CL	MNL	DNL	SNL
ITS	CL	-	N	N	N	-	N	N	N
	MNL		-	N	N		-	N	N
	DNL			-	N			-	N
	SNL				-				-
Flow	CL	-	Y	N	Y	-	Y	N	N
	MNL		-	N	Y		-	N	N
	DNL				N			-	N
	SNL								-
Toughness	CL	-	N	N	N	-	N	N	N
	MNL		-	N	N		-	N	N
	DNL			-	N			-	N
	SNL				-				-

Note: CL: control lime,MNL: modified nano lime, DNL: dry nano lime, SNL: slurry nano lime Y: P-value < α = 0.05 (significant difference); N: P-value > α = 0.05 (No significant difference)

TSR analysis

Tensile strength ratio is usually used to identify the ratio of wet ITS to dry ITS values and avoid the moisture induced damage in dry and wet condition. TSR results are presented in Figure 4. It can be noted that all mixtures have TSR values higher than 80% (the minimum value set forth by AASHTO) regardless of lime and aggregate types. TSR values of mixtures from aggregate B are the highest as using nano lime. In most cases, TRS values from MNL, DNL, and SNL satisfy the requirements by specification.

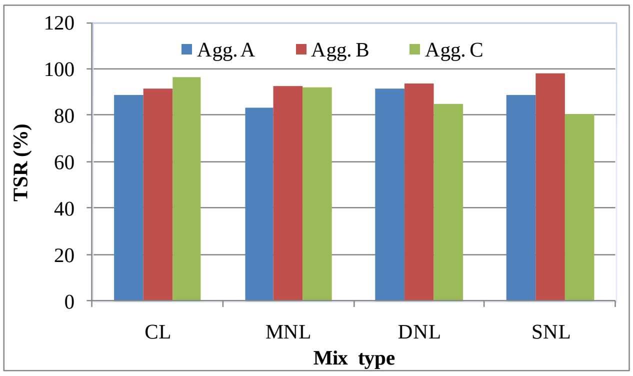
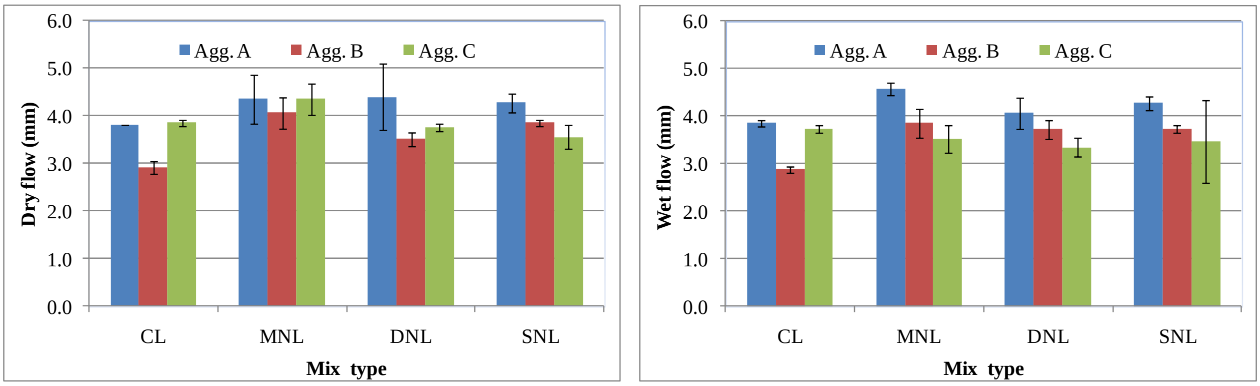


Fig. 4 TSR values

Deformation analysis

The deformation (flow) resistance of dry ITS specimens, a measure of the material's resistance to permanent deformation in service and related to its stiffness [8], was used for moisture susceptibility analysis of the mixtures [8]. The flow is the total deformation value from the beginning of loading until the loads begins to decrease. As shown in Figure 5(a), the deformation results indicate that, in general, the mixtures from aggregate B show lower dry flow values than mixtures from aggregates A and C. Beside the aggregate properties, another contributing reason is the fact that mixtures made from aggregates A and C had higher optimum asphalt binder contents. In addition, in most cases, mixtures with nano lime have greater flow values than regular hydrated lime in this study. Amongst three nano lime mixtures, MNL mixtures generally have slight higher dry flow values than DNL and SNL mixtures. Statistical analysis shown in Table 4 indicates that the dry flow values of CL mixtures are significant difference with MNL and SNL mixture. In addition, MNL mixtures have significantly different dry flow values with SNL mixtures. There are no statistically different dry flow values between any other two mixtures.

The wet flow value shown in Figure 5(b) indicates that, mixtures with nano lime form aggregates A and B have higher flow values than mixtures with regular lime. Mixtures with nano lime from aggregate C have the lowest wet flow values while these flow values of mixtures from aggregate A are the highest. In addition, these mixtures containing nano lime generally have similar wet flow values as made from same aggregate. Statistical results in Table 4 illustrate that, mixtures containing regular lime (CL) have significantly different wet flow values with mixtures containing MNL. There are no significant different wet flow values between any other mixtures.

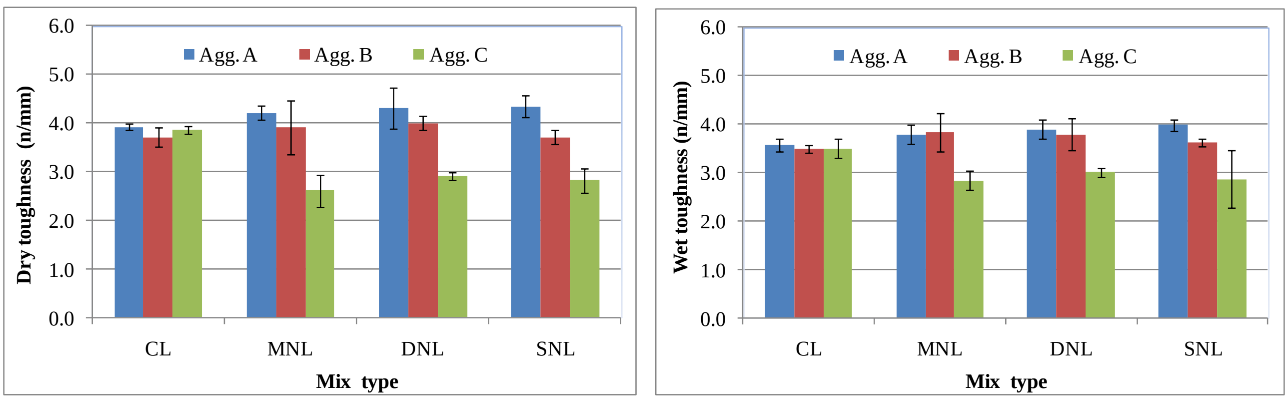


(a) (b)

Fig. 5 Dry and wet flow values

Toughness analysis

Toughness is defined as the area under the tensile stress-deformation curve up to a deformation of twice that incurred at maximum tensile stress [3, 8]. The toughness results of dry ITS specimens are shown in Figure 6(a) and statistical analysis is presented in Table 4. It can be noted that, in most cases, the dry toughness values of specimens from aggregates A and C are similar regardless of nano lime or regular lime, however, mixtures from aggregate C with nano lime have lower toughness values than mixtures with regular lime form same aggregate. In addition, the toughness values of mixtures with MNL, DNL, and SNL generally are close. Moreover, the wet toughness values of mixtures exhibit similar trends with dry toughness values. Statistical analysis in Table 4 illustrates that there are no significant difference in dry and wet toughness values between any two mixtures such as mixtures containing nano lime or regular lime.



(a) (b)

Fig. 6 Dry and wet toughness values

FINDINGS AND CONCLUSIONS

The following conclusions were drawn based upon the experimental results obtained from the mixtures with or without nano lime in terms of three methodologies of producing nano lime mixtures:

- More compaction efforts are required to achieve target air voids for mixtures from aggregate B. However, mixtures from aggregate C generally have the lowest gyration number in this study. Compared to regular hydrated lime mixtures (CL), mixture with nano lime mixtures from aggregate A have slightly greater gyration numbers. No obvious gyration number trends are found in terms of three methodologies in general.
- Mixtures from aggregate B have the greatest wet ITS values. In addition, MNL mixtures have close or less wet ITS with CL mixtures while the wet ITS value of DNL and SNL mixtures are generally higher regardless of aggregate type.
- All mixtures have TSR values higher than 80% regardless of lime and aggregate types. TSR values of mixtures from aggregate B are the highest as using nano lime.
- Mixtures with nano lime have greater flow values than regular hydrated lime in this study. Amongst three nano lime mixtures, MNL mixtures generally have slight higher dry flow values than DNL and SNL mixtures.
- In most cases, dry toughness values of specimens from aggregates A and C are similar regardless of nano lime or regular lime, however, mixtures from aggregate C with nano lime have lower toughness values than mixtures with regular lime form same aggregate. In addition, the toughness values of mixtures with MNL, DNL, and SNL generally are close.

ACKNOWLEDGEMENT

This research was funded by Faculty Research Grant, Georgia Southern University. Without this funding, it would be impossible to complete the research project.

REFERENCES

[1] Xiao, F., Amirkhanian, S.N., and Juang, H.C. 2007, Rutting resistance of rubberized asphalt concrete pavements containing reclaimed asphalt pavement mixtures. Journal of Materials in Civil Engineering, Vol. 19, No. 6, pp. 475-483

[2] Kringos, N., Scarpas, A., Copeland, A., Youtcheff, J., 2008, Modelling of combined physical-mechanical moisture-induced damage in asphaltic mixes Part 2: Moisture susceptibility parameters, International Journal of Pavement Engineering, v 9(2), p129-151

[3] Xiao F. and Amirkhanian S.N. 2009, Laboratory investigation of moisture damage in rubberized asphalt mixtures containing reclaimed asphalt pavement, International Journal of Pavement Engineering, Vol.10, No.5, pp.319-328

[4] Taylor, M. A. and Khosla, N. P., Stripping of asphalt pavements: state of the Art. *Transportation Research record* 911, Washington, D.C., pp 150-158, 1983.

[5] Lu Q, and Harvey, J.T., 2006, Laboratory Evaluation of Long-term Effectiveness of Antistripping Additives, Journal of Transportation Research Board, No. 1970, pp. 14-24, 2007
[6] Kim, K. W., and Amirkhanian, S. 1991, Evaluation of effectiveness of antistrip additives using fuzzy set procedures, Journal of Transportation Research Board, No.1323, Washington DC
[7] Shen, J., Huang, B., Shu, X., Tang, B. (2010a) Influence of Nano-Sized Hydrated Lime (HL) on Selected Properties of Hot-Mix Asphalt (HMA), in press, International Journal of Pavement Technology and Research.
[8] Xiao F., Jordan J., Amirkhanian S.N. 2009, Laboratory investigation of moisture damage in warm mix asphalt containing moist aggregate, Journal of Transportation Research Board, Vol. 2126, pp. 115-124