Toughness Performance of Recycled Aggregates for use in Road Pavement

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Abstract

The policy of driving organization such as Highways Agency is towards the use of performance related specifications. This policy and adoption of European wide aggregate standards on the one hand, and sustainable construction pressures on the other, all strongly emphasize on further need for more developments to specifications and performance assessment methodologies instead of creating barriers to the use of suitable materials. Performance related specifications for pavement foundations are being developed and are primarily based around in-situ control and compliance testing. Laboratory based tools for assessment of the performance of foundation materials and their durability under adverse conditions would be a key factor to the successful use of alternative materials.

The toughness performance of recycled concrete aggregates (RCA) mixed with natural aggregates (NA) was evaluated based on the test specifications given in the NCHRP Report 598. For this purpose Los Angeles Abrasion and degradation test results were correlated with established Micro-Deval designations in NCHRP report 598.Three main factors involved in performance assessment; i.e. (a) traffic loading, (b) moisture levels in highway pavements and (c) the temperature conditions. The research study showed that the materials were appropriate for unbound subbase for medium traffic in non freezing condition from the standpoint of toughness. Also they are suitable for low traffic situations with low moisture and freezing weather.

Keywords: Recycled aggregate, toughness, performance, pavement

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1. Introduction

Many projects and research studies use accelerated pavement testing to assess potential construction materials, pavement designs, and other pavement-related aspects. The disadvantage of this method is that long-term strength loss because of poor durability and frost effects cannot be fully evaluated [NCHRP Report 598, 2008].

Testing in-service pavements is sometimes proposed to evaluate the requirements of aggregates in actual practice. This approach investigates the adaptability of the recommended test results of codes and standards to the results of testing under real traffic loading. But it will generally take several years before performance data become available [NCHRP Report 598, 2008].

Research study carried out at Nottingham University by Hill and co-authors (2001), using performance based specifications concluded that many alternative materials performed just as well as and in some cases even better than conventional materials. The research study showed that the stiffness and strength properties of bound materials were dependent on the coarsest fraction of the material and the amount of binder. Coarse fraction of materials had a higher stiffness than fine materials and also needed less binder to gain a particular strength [Hill et al, 2001].

In France a national project called CAREX (2003–2005) was set up in order to help bridge the gap between current level of knowledge and the reality of using alternative materials in highways. Based on a stress-response approach applied to both the alternative material and the road structure and with the details of external factors, a standard framework for field data classification and analysis was implemented. To perform this analysis, a set of 17 documented field experiments was identified through a specific national survey and performed on 12 alternative materials. Seven of the materials were used in subbase while 5 were used in road base. Structure monitoring was usually brief and mechanical loads too weak, which limits the importance of field testing. Therefore future testing methods should take into account the actual field conditions [François et al. 2009].

Edwards et al. (2006) attempted to increase the application of alternative materials through adopting performance related specifications, rather than the more traditional methods, which tend to favour materials from established aggregate sources. Edwards (2003) detailed the changes to material specification and the range of recycled and secondary aggregates which can be used within highway works. As a consequence of the work of Edwards (2007), a range of recycled and secondary materials was detailed according their appropriate areas of application in highway construction. This made it possible to publish a series of guidelines on the potential use of different materials. An extension and simplification of existing guidance was produced through this study.

Saeed (2006) concluded that the properties that affect performance of unbound granular pavement layers include shear strength, stiffness, frost susceptibility, toughness and abrasion, durability and permeability.

A comprehensive research study at Sustainable Technology Research Center (STRC) of Kingston University was conducted on different sources of recycled concrete aggregates (RCA) mixed with natural aggregates (NA) and reclaimed asphalt pavement (RAP).The overall objective of this research study was to study the performance of the mixes applied in unbound pavement layers based on the protocol introduced in previous literatures. Current paper includes the assessment of toughness potential for RCA blended with NA from the resources based in Iran. The research study methodology and scope presented in this paper can be a framework for other performance potential assessments.

2. Background of Employed Protocol

For recycled aggregates in unbound pavement layers, NCHRP Report 598 (2008) in conjunction with AASHTO proposed a set of recommendations, for defining the performance-related tests. The objective of the research study in the NCHRP Report 598 was to develop a process for selecting recycled hot-mix asphalt (HMA) and Portland cement concrete (PCC) materials and performing performance-related tests on these materials before use in unbound layers.

The NCHRP Report 598 describes various types of distress, along with relevant contributing factors, in flexible and rigid pavements. The cross-relationships between the performance parameters, aggregate properties and relevant laboratory test methods are listed in Table 1, for flexible pavements.

Table 1. Links between aggregate properties and performance [NCHRP Report 598, 2008]

Pavement type	Performance parameter	Related aggregate property	Test measures
Flexible	Fatigue Cracking	Stiffness	Resilient modulus, Poisson's ratio, gradation, fines content, particle angularity and surface texture, frost susceptibility degradation of particles, density
	Rutting Corrugations	Shear Strength	Failure stress, angle of internal friction, cohesion, gradation, fines content, particle geometrics (texture, shape, angularity), density, moisture effects
	Fatigue Cracking, Rutting, Corrugations	Toughness	Particle strength, particle degradation, particle size, gradation, high fines
		Durability	Particle deterioration, strength loss
		Frost susceptibility	Permeability, gradation, percent minus 0.02 mm size, density, nature of fines
		Permeability	Gradation, fines content, density

To ensure specification compliance, and to investigate the strength and durability properties, laboratory tests should be carried out to establish the characteristics of aggregates as construction materials. NCHRP developed a series of laboratory tests, mostly along empirical lines, to estimate performance and to identify potentially poor performers. The proportions and properties of RAP and Reclaimed Concrete Pavement (RCP) in the mixes of unbound pavement layers have a significant impact on the performance of the layer. Because of the particulate nature of unbound aggregate layers, their mechanical properties also depend on the stress state and environmental conditions. For pavement applications, tests have been developed to measure different categories of aggregate properties and characteristics such as toughness.

Table 2 lists the toughness potential test methods and their comparative rankings in applicability to the evaluation of recycled aggregates.

Table 2. Rating of toughness potential test methods for evaluating recycled aggregates [NCHRP Report 598, 2008]

Property measured	Test	Performance predictability	Accuracy	Practicality	Complexity	Precision	Cost	Composite
Toughness	LA Abrasion	Fair	Fair	Medium	Simple	Fair	Low	Medium
	Aggregate Impact Value	Fair	Fair	Fair	Simple	Fair	Low	Medium
	Aggregate Crushing Value	Fair	Fair	Fair	Simple	Fair	Low	Medium
	Aggregate Abrasion Value	Poor	Poor	Poor	Fairly Simple	Poor	Low	Low
	Micro-Deval	Good	Fair	Medium	Simple	Fair	Low	Medium
	Durability Mill	Poor	Poor	Poor	Fairly Simple	Fair	Medium	Low
	Gyratory Test	Poor	Poor	Poor	Fairly Simple	Fair	Medium	Low

In this research study, traffic levels and its combination with climate condition are according to Tables 3 and 4, respectively.

Table 3. Traffic levels [NCHRP 453, 2006]

Traffic Level	Number of ESALs/year
Low traffic	<100,000 ESALs/year
Medium traffic	100,000–1,000,000 ESALs/year
High traffic	>1,000,000 ESALs/year

ESAL in Table 3 is the acronym for Equivalent Single Axle Load.

The climatic conditions of moisture and freezing were chosen based upon the AASHTO definitions. Table 4 shows the significance levels of traffic, moisture, and climate combinations on a scale of 1 to 4, where 4 is the most significant and 1 is the least significant on potential of aggregate performance.

Table 4. Significance levels of traffic, moisture and temperature combinations on aggregate performance potential [NCHRP 453, 2006]

Temperature Condition	Moisture Condition	Traffic		
		High	Medium	Low
Freezing	High	4	4	3
	Low	4	3	2
Non Freezing	High	3	2	2
	Low	3	2	1

Recommended parameter values from prescribed tests for use in assessing the toughness potential performance of recycled aggregates under different combinations of traffic (high, medium or low), moisture (high or low) and temperature conditions (freezing or non-freezing) are listed in Table 5.

3. Materials

3.1 Recycled Concrete Aggregate (RCA)

RCA was produced by demolishing the walls and piles of the Amir Kabir tunnel, located in central Tehran, as result of refurbishing of the tunnel. As most concrete demolished pieces at the initial stages are oversized (See Fig.1), it was decided to crush the concrete pieces using pneumatic hammer to produce both coarse and fine aggregates to satisfy the subbase grading. Determining soluble silica based on ASTM C 1084 showed that, the soluble silica content in crushed concrete was 3.12% [ASTM C 1084-02]. The cement content of concrete according to this analyses obtained $315 kg/m^3$.

Figure1. Demolished walls and piles

3.2 Natural Aggregates (NA)

Natural aggregates (NA) were obtained from Kan River located in North West Tehran. These aggregates were mostly rounded corner and the oversize particles were separated manually (Figure 2).

Table 5. Recommended tests and test parameters for levels of intended use in recycled aggregates [NCHRP Report 598, 2008]

Tests	Traffic	H		M		H		L	M		L		
	Moisture	H	L	H	L	H	L	H	H	L	L	H	L
	Temperature	F	F	F	F	NF	NF	F	NF	NF	F	NF	NF
Toughness/Abrasion Micro-level, MD		< 5%			< 15%				< 30%				< 45 %

Figure 2. Natural river aggregates

In this study, a portion of natural aggregate was replaced by recycled concrete aggregate and used as the subbase materials. The replacement levels were 20% and 50% by weight of the RCA, so that the mix designs applied to tests were:100%NA as control mix, 80%NA+20%RCA, 50%NA +50%RCA, 20%NA+80%RCA and 100%RCA. The particle sieve distributions of these mixtures were within type II subbase grading curves according to Iran Highway Asphalt Paving Code (2003) (Table 6).

Table 6. Grading sizes for NA and RCA mixes

Sieve No.	Lower Percent	Upper Percent	100%NA	20%RCA+ 80%NA	50%RCA+ 50%NA	80%RCA+ 20%NA	100%RCA
2"	100	100	100	100	100	100	100
1.5"	90	100	95.09	94.30	90.27	89.98	94.10
1"	75	90	90.40	80.90	79.97	78.30	75.56
3/4"	-	-	81.12	71.10	70.91	67.44	66.38
1/2"	-	-	73.62	59.00	61.11	55.31	52.90
3/8"	40	70	66.80	51.00	55.76	49.20	43.35
NO.4	30	60	52.13	40.70	43.28	37.65	29.78
NO.10	20	50	30.01	25.40	28.87	25.76	20.67
NO.20	-	-	17.46	18.30	20.51	20.20	15.87
NO.30	-	-	14.44	16.20	18.00	18.56	14.33
NO.40	10	30	12.52	15.00	16.29	17.45	13.41
NO.50	-	-	10.50	13.70	14.52	16.05	12.02
NO.100	-	-	5.90	12.70	12.24	12.70	9.93
NO.200	0	12	4.49	12.00	9.76	7.88	9.50

4. Tests and Results

4.1 Los Angeles Abrasion (LAA)

A 10 kg sample of 100%NA and 50%NA+50%RCA prepared according to Grading B (including 2500 gr of aggregates passing from 19.0 mm and retained from 12.5 mm plus 2500 gr of aggregates passing from 12.5 mm and retained from 9.5 mm) and subjected to Los Angeles abrasion test following ASTM C131-06(2006). The test required that each sample be placed with 12 steel spheres inside a metal drum that rotated at 30 revolutions per minute for 1000 revolutions. The weight loss in percentage by abrasion and impact was calculated from the original total mass and the final mass obtained after samples were washed over a No.12 (1.70 mm) sieve and oven dried at 110°C.For other mixtures such as 80%NA+20%RCA, 20%NA+80%RCA and 100%RCA in accordance with ASTM C535-03(2003) the grading designation 2 (including 5000 gr of aggregates passing from 50.0 mm and retained from 37.5 mm plus 5000 gr of aggregates passing from 37.5 mm and retained from 25 mm) was chosen because of the available aggregate particles.

Los Angeles abrasion (LAA) losses for each of the materials are largely consistent with the values reported by other research studies [Blankenagel and Geuthrie, 2006 and Taha et al., 2002]. The results are summarized below:

Mix type	Weight loss in LAA
100%RCA	31%
20%NA+80%RCA and 50%NA+50%RCA	30%
80%NA+20%RCA	28%
100%NA	24%

Therefore, in general the weight loss in LAA decreased as the level of replacement of RCA with NA increased. It is clearly evident that replacing RCA with NA decreased the amount of fine materials produced from stripping of cement paste during LAA testing [Blankenagel and Geuthrie, 2006]. In the LAA test, NA particles are more resistant to impact forces of the steel spheres in comparison to RCA. An advantage of less particle breakdown is that the percentage of fine particles is decreased. Consequently the less change in gradation of the material, if used as a highway pavement subbase, provides enhanced stiffness to support in-service loads. Additionally, such a gradation change results in decreased water absorption potential and improved drainage properties of unbound subbase made with the mix of RCA and NA. As is seen from Figures 3 and 4, degradation of NA was much less than that of RCA.

4.2 Degradation

To evaluate changing the size of aggregates after crushing under roller passes, sieve analyses was performed on aggregates passing the 3/4" sieve before and after compaction test which can cover CBR samples performance as well (Figs. 3 and 4). As can be seen in Fig. 3, significant degradation was observed in the coarse size particles of RCA. For example, at size 4.75 mm (sieve No. 4) the difference between the percentage passing before and after compaction was found to be slightly more than 20%. As for the NA material, Fig. 4 shows that change in gradation due to compaction was much less significant.

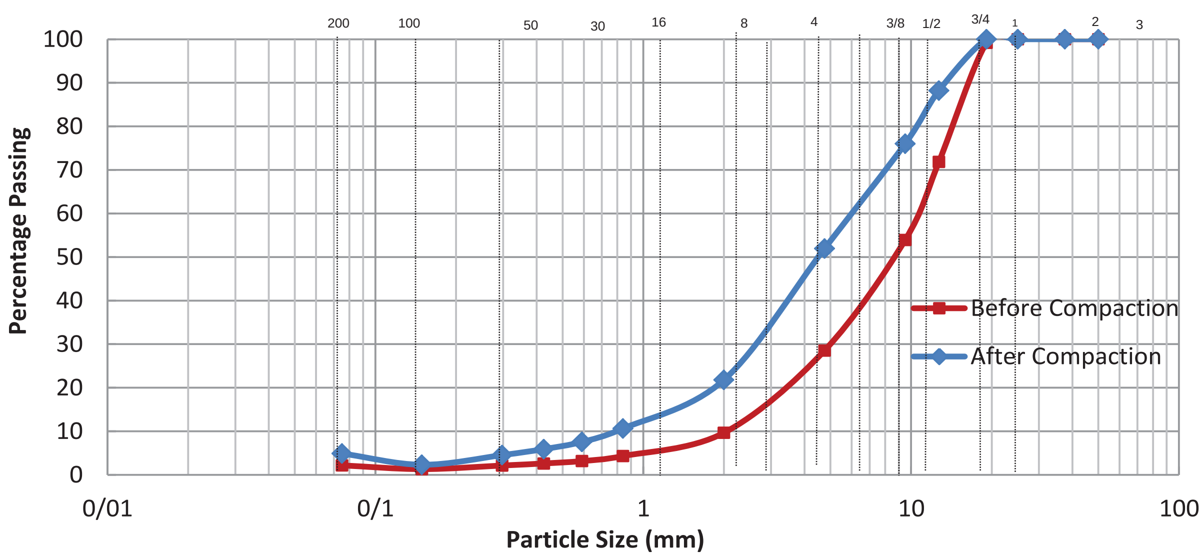

Figure 3. Sieve analysis of RCA compacted sample

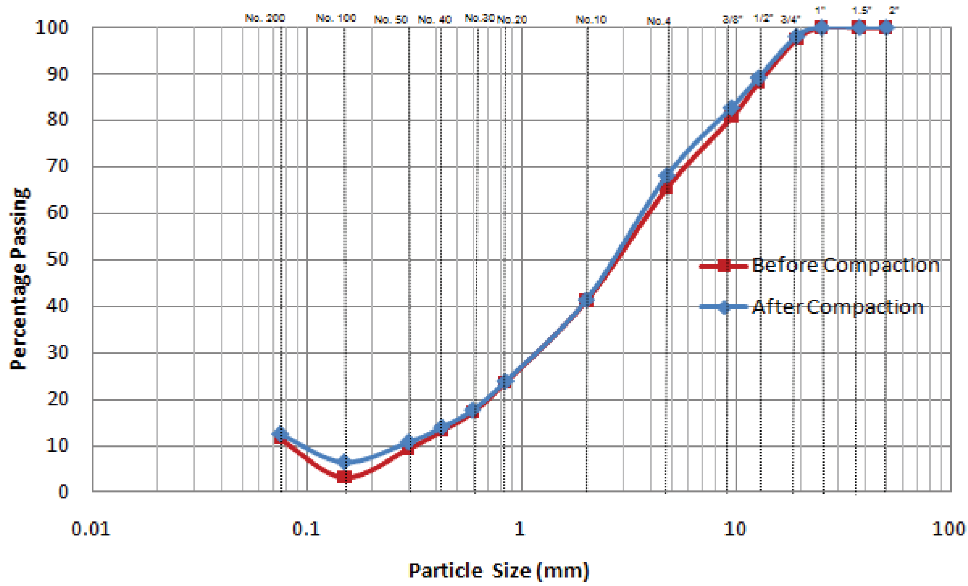

Figure 4. Sieve analysis of NA compacted sample

4.3 Performance Potential Based on Toughness

In Table 2 the Micro-Deval (MD) test was rated as "good", but other tests were ranked as "fair". It should be recognized that the degradation of compacted samples is a simplified and practical simulation of the gyratory degradation test described in NCHRP 453 for natural aggregates. Paranavithana and Mohajerani (2003) also used the gyratory degradation test in their research study relating to RCA. As was illustrated in Table 5, the MD test is the recommended method for assessing the toughness/abrasion potential of natural and recycled aggregates. As such the results of other tests, if done instead of MD test, should be transformed into the equivalent MD test value before using Table 5. However, this is not easily achieved because at present there are few published correlations between, say LAA and MD values, and also these correlations suffer from low reliability. As an example, a scatter diagram of LAA versus MD values reported by Rangaraju and Edlinski (2008) is illustrated in Figure 5. This chart was plotted from a study of some aggregates used in hot mix asphalt (HMA). The author's tests showed that all aggregates with LA abrasion of less than 35% had the MD of less than 23.5% [Ayan, 2011]. These limits are annotated in Fig. 5 to have an approximate way of using LAA values to predict what the MD values of the materials tested in the research study would have been.

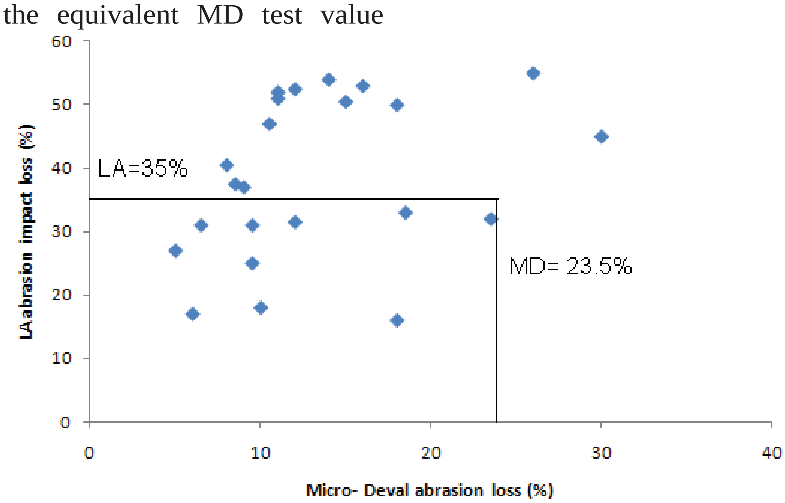

Figure 5. The chart showing the likely range of MD values corresponding to LAA< 35% [Rangaraju and Edlinski, 2008]

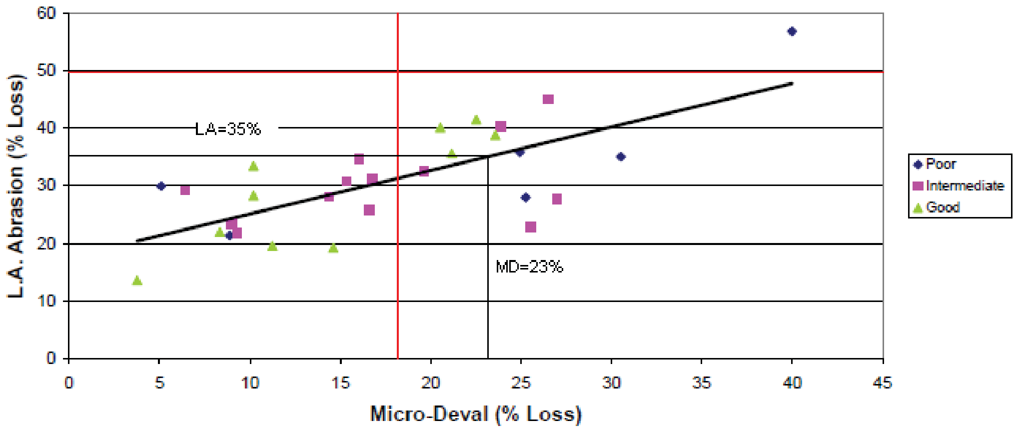

Figure 6. L.A. Abrasion vs. Micro-Deval [Williamson, 2005]

Williamson (2005) presented a chart for correlating LAA and MD values for natural and recycled aggregates. The chart, which is shown in Figure 6, indicates a less degree of scatter (i.e. a better correlation) as compared to the data points in Fig. 5. Remarkably for LAA=35% (the maximum value observed in the author's data collected and investigated in [Ayan, 2011] the corresponding MD=23%, which is consistent with the author's suggestion.

All aggregates tested had LAA of less than 31% apart from the 100%RCA which had LAA=31%. Based upon the author's suggested correlation from Figs. 5 and 6 the corresponding MD is judged to be equal or less than 30%, which meets the requirements of significance levels of 1,2.

5. Conclusions

As has been discussed, all the publications examined are in agreement that MD is the most appropriate test for assessing toughness of aggregates. In addition, for assessment of the overall performance of recycled aggregates other supporting tests are also necessary. This is why the present research study has included other tests such as LAA degradation of aggregates to replace MD test values. The overall results of toughness properties showed that:

- Degradation of 100%RCA is increased by the process of extraction of RCA, which may mean that cement mortar attached to the aggregates is crushed or partly detached from the aggregates causing weakness in RCA. This is manifested in the results of the other toughness tests such as LAA and MD.
- In summary, it is seen in Table 8 that for all tested materials, the significance level was always either 1 or 2. This implies that from the viewpoint of toughness, the materials investigated here would be appropriate for unbound subbases for medium traffic in non freezing condition. Also they are suitable for low traffic situations with low moisture and freezing weather.

Table 8. Performance potential based on toughness

Aggregate	Test Result	Significance Level
100%NA	LAA=24% Degradation=Medium	1, 2
80%NA+20%RCA	LAA=28%	1, 2
50%NA+50%RCA	LAA=30%	1, 2
20%NA+80%RCA	LAA=30%	1, 2
100%RCA	LAA=31% Degradation=High	1, 2

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