Research progress of aggregate mechanics test methods

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Abstract—Aggregate mechanical properties directly affect the structural performance of asphalt mixtures. Aggregates must be hard and wear-resistant, with the ability to resist disintegration to ensure good pavement performance. Appropriate and effective experimental evaluation methods of aggregate properties will contribute to a better understanding of material performance. This paper reviewed the literature on the applications of various types of aggregate mechanical test methods and analyzed the relationships among them. Aggregate degradation changes the aggregate gradation, and hence the volume characteristics of the asphalt mixture. Aggregate degradation in different compaction processes of asphalt mixtures during construction was described, and related influencing factors were analyzed. Finally, suggestions were made to overcome the deficiencies of the existing test methods and the problem of aggregate degradation.

1. Introduction
Aggregate is the most commonly used material in highway engineering, accounting for 75-85% of the volume of cement concrete and 93-95% of the volume of asphalt mixture, which has a great impact on the pavement structure and function[1][2]. The aggregate must have a certain quality and be able to withstand traffic loads and environmental conditions. The aggregate should have sufficient toughness and wear resistance to resist the impact and wear of the tire[3].

At present, researchers have proposed a variety of experimental methods to evaluate the mechanical properties of aggregate. A few methods have been widely used, such as Los Angeles abrasion and impact test, coarse aggregate impact value test, coarse aggregate crushing value test, micro-Deval test and magnesium sulphate soundness test or sodium sulfate soundness test[4][5].

In pavement construction, the asphalt mixture is repeatedly compacted after paving. After opening the traffic, the asphalt pavement has to bear heavy traffic loads. Both of these situations cause the aggregates degradation, which in turn will result in change of aggregate gradation, deviating from the original mix design. Therefore, the phenomenon of aggregate degradation should be paid attention to by researchers. Aggregate is an indispensable raw material for construction engineering. It is very important to study the mechanical properties of aggregate and put forward more effective test methods and evaluation indexes to ensure the quality of aggregate.

2. Determination of Mechanical Properties of Aggregates

2.1. Introduction of aggregate mechanics test methods
Aggregate mechanics test methods vary from country to country, and some tests can be performed based on different standard test methods such as the standard by American Society for Testing and
Materials, ASTM and European Committee for Standardization, CEN. The common test methods of aggregate mechanics are introduced below.

2.2. Micro-deval test
Micro-deval test (MD) is the basis of most current standards. It is considered to be the most commonly used test for the wear resistance of aggregate Methods[4]. The micro-deval test considers the degradation caused by mechanical wear and weathering, and better simulated field conditions. At the same time, the test includes the effect of moisture on aggregate wear resistance, which could not be determined by the Los Angeles wear test[5]. The micro-Deval test on fine aggregate has been adopted by the Canadian Standards Association as an alternative test for the magnesium sulphate soundness test for concrete sand[6][7].

2.3. Los Angeles Abrasion Test
The Los Angeles Abrasion Test (LAAI) was originally developed in Los Angeles in 1920[8]. A survey of 48 states in the United States shows that 96% of institutions uses the Los Angeles abrasion test[9].

This test procedure involves placing a washed and oven-dried sample of aggregate 5,000 g of specific gradation, in a large steel drum, along with a specified number of steel spheres. The aggregate sample is then subjected to abrasion and impact loading by rotating the steel drum at a specified rate of revolutions per minute. After 500 revolutions, the degradation in the aggregate is determined by sieving the aggregate sample over a 1.70 mm sieve and expressing the material passing through as a percent of the original sample mass[10].

In addition to representing the wear loss of Los Angeles by sieving aggregate, some researchers analyze the wear test process of Los Angeles with advanced imaging technology, which is beneficial to insight into the mechanical behavior of aggregate particles during the wear process[11][12].

2.4. Sulfate Soundness Test
Sulfate Soundness Test is probably one of the most famous tests used today in the United States and the European Union to assess the weathering resistance of aggregates, especially the disintegration resistance of freeze-thaw cycles[13][14]. There are several differences between EN and ASTM soundness tests. Both magnesium sulfate and sodium sulfate can be used in ASTM soundness test. While the EN test clearly prescribes the use of magnesium sulphate heptahydrate. However, the validity and repeatability of the trial have been questioned by researchers across the United States[13]. Ioannis Ioannou believes that minor changes during the test may cause significant differences in the final calculated loss rate[14]. Kline et al. believed that sieving aggregates between each cycle may lead to changes in results[15]. Therefore, sulfate soundness test should be studied in detail to identify the stages leading to variable test results.[16]

2.5. Aggregate Crushing Value
The coarse aggregate Crushing Value test (ACV) is derived from British Standard 812. This test consists of applying a load to an aggregate sample in a steel cylinder for 10 minutes. After the 10 minute loading period the sample is analyzed for changes in gradation and a value is determined. Although this test is not adopted by ASTM and CEN, it is still used in many literatures to evaluate the mechanical properties of aggregates[17][18].

2.6. Aggregate Impact Value
The coarse aggregate impact value test (AIV) is used to measure the impact resistance of the aggregate. After drying the aggregate with particle size of 9.5mm~13.2mm, put it into the measuring cylinder in three layers, and tap each time with the rammer for 25 times. Then pour the aggregate into the impact cup and pound 15 times. The crushed material is taken out of the cup and the aggregate quality is
determined through a 2.36mm square hole sieve. The test equipment is cheap, easy to carry and operate and less aggregate consumption[18].

Petrographic test is an important method to evaluate the quality of rock aggregates. Among the petrological characteristics, some texture characteristics such as particle shape, size and arrangement of mineral grains, porosity, matrix content and grain interlocking degree seem to play an important role in determining aggregate performance[17]. For pavement materials, petrographic inspection mainly provides the types of aggregate minerals or rocks in cement concrete, and the physical and chemical properties of the aggregates, especially the types and contents of ingredients that may undergo alkali aggregate reaction [19][20].

3. Research progress of aggregate mechanics test
In recent years, researchers have conducted extensive research on the correlation between different experiments. Horst g. Brandes[21] conducted different mechanical tests on aggregates in Hawaii, and the data showed that the Los Angeles abrasion test, crushing value test and impact value test were highly correlated. Massoud [22] also analyzed the relationship among the Los Angeles abrasion value, impact value and crushing value of different types of aggregates. The study believed that the three tests were highly correlated, and the aggregate impact value could predict the aggregate crushing value well, which was in good agreement with previous studies. Jenny LIU et al. [23] verified the feasibility and repeatability of the micro-deval test to assess aggregate durability in Alaska. Gregory s. Williamson[17] carried out a variety of aggregate performance tests on 74 aggregates from Wisconsin, indicating that the correlation between the two attrition losses was not strong. Many other literatures also reached similar conclusions[24]-[29]. The correlation between Los Angeles abrasion test and micro-deval test is not strong, indicating that two methods evaluate different mechanical properties of aggregates. There is a strong correlation between Los Angeles abrasion test and the aggregate crushing value test, which means that the Los Angeles abrasion test shows more the strength of aggregate than the wear resistance of aggregate. The micro-deval test measures the wear resistance of the aggregate.

The researchers try to relate the results of the aggregate abrasion test to the on-site performance of the aggregate. They are also working on the ability to predict long-term pavement performance for aggregate mechanics tests. According to Horst G. Brandes[21], it shows that the correlation between the micro-deval abrasion test and pavement performance is stronger than that of the Los Angeles abrasion test and aggregate crushing value test. From other literatures[30], it can be concluded that micro-deval abrasion test can predict the overall performance better than Los Angeles abrasion test.

At present, some foreign researchers use regression analysis to predict the mechanical strength of aggregates based on the physical and mechanical properties of rocks, including point load index (PLI), Schmidt hardness (SCH), uniaxial compressive strength (UCS), and porosity[31]-[36].

The coefficient of correlation between each pair of mechanical tests in the previous literatures is listed in Table 1.

| Variables | Rock type | R² or R | Equation | Reference |
|-----------|-----------|---------|----------|-----------|
| LAAI vs. AIV | Charnockite, Charnockitic Gneiss | R²=0.692 | LAAI = 1.115AIV + 5.627 | Mohammad Khaleghi Esfahani et al.(2019) |
| | Limestone, travertine, basalt, | | | |
### 4. Degradation of aggregate in asphalt mixture

In the process of compaction molding, aggregates resist external forces through interlocking force, frictional resistance, viscosity, etc. When the component of the force applied in any direction is greater than the resistance, the aggregate will move until it reaches a more stable position. When the aggregate particles are adjusted to the new position, the force will cause the fracture and wear of the contact point. This phenomenon is called aggregate degradation, which reduces the size of the aggregate particle size and changes the gradation of the aggregate, leading to the decrease of the void volume and the increase of the density of the asphalt mixture.

This problem has already attracted the attention of researchers[37]. Recently, the Maine Department of Transportation observed premature failure of its HMA pavements because of loss of material in the wheelpaths. Todd Lynn[38] sampled the mixture in each process of construction to examine the aggregate degradation during this process. It showed that a large number of aggregate degradation had taken place, which had a great impact on the volume characteristics of the mixture. Through various types of laboratory compaction tests, the researchers try to simulate the impact of construction...
equipment and traffic on aggregate degradation. Ronald and Donald[39] studied gradation changes resulting from compaction and suggested that if aggregates with excessive wear losses were used in the mix design during the test phase, adjustments to the formula gradation of the working mix might be require. In F. Moavenzadeh and W.H.Goetz[41], they further analyzed the factors affecting the aggregate degradation, indicating that aggregate degradation followed a certain pattern regardless of the particle size, gradation and rotational compaction revolution. Previous studies[40][42] indicated that the Marshall compactor fractured aggregate more often during compaction than the other compactors. Besides, aggregate gradation was found to be the most important factor affecting degradation. When open-graded mixes are used, the aggregates should be less resistant to degradation than those used in denser mixes.

So far, most of the studies have only indicated the occurrence of aggregate degradation through sieve analysis. Some literature mentioned the method of calculating the increase of area under the distribution line and surface area before and after aggregate degradation [43].

Aggregate degradation is an important and complex problem, researchers should pay more attention to the mechanism of aggregate degradation.

5. Discussion and suggestions
Since the 1930s, several aggregate test methods have been used to evaluate the mechanical strength of aggregate and to predict the performance of aggregate. This paper reviews the application progress of commonly used aggregate mechanics test methods, and proposes that aggregate degradation should arouse the researchers' attention. Based on the findings of this review, the following suggestions are recommended for future research:

- The existing mechanical test methods mostly use the percentage change of a certain sieve to characterize aggregate strength, which can not clearly and comprehensively describe the degree of aggregate crushing. In the future, more analytical methods should be sought to evaluate the degradation of aggregates, and the degradation process and mechanism of aggregates should be analyzed from different perspectives.
- Only from the perspective of reducing the degradation of aggregates in asphalt mixtures, the use of aggregates with higher Loss Abrasion values for dense graded asphalt mixtures effectively avoids the massive degradation of aggregates in open graded mixtures.
- Researchers should consider how to predict the degradation amount of asphalt mixture and how to reduce or avoid the influence of aggregate degradation on the volume performance of asphalt mixture in the design process.

REFERENCES
[1] Esfahani M K , Kamani M , Ajalloeian R . An investigation of the general relationships between abrasion resistance of aggregates and rock aggregate properties[J]. Bulletin of engineering geology and the environment, 2019, 78(6):3959-3968.
[2] Ajalloeian R , Kamani M . An investigation of the relationship between Los Angeles abrasion loss and rock texture for carbonate aggregates[J]. Bulletin of Engineering Geology and the Environment, 2017.
[3] Bahrami K , Aghda S M F , Noorzad A , et al. Investigation of Abrasion and Impact Resistance of Aggregates in Different Environments in Direh, Kermanshah, Iran[J]. Geotechnical & Geological Engineering, 2018, 37(4).
[4] Dennis, Gatchalian, Eyad. Characterization of Aggregate Resistance to Degradation in Stone Matrix Asphalt Mixtures:[J]. Transportation Research Record, 2018.
[5] Ugur I , Demirdag S , Yavuz H . Effect of rock properties on the Los Angeles abrasion and impact test characteristics of the aggregates[J]. Materials Characterization, 2010, 61(1):90-96.
[6] Rogers C A , Bailey M L , Price B . MICRO-DEVAL TEST FOR EVALUATING THE QUALITY OF FINE AGGREGATE FOR CONCRETE AND ASPHALT[M]. 1991.
[7] Senior S A . Laboratory Tests for Predicting Coarse Aggregate Performance in Ontario[J]. Transportation Research Record Journal of the Transportation Research Board, 1991, 1301(1301):97-106.

[8] Markwick A H D , Shergold F A . THE AGGREGATE CRUSHING TEST FOR EVALUATING THE MECHANICAL STRENGTH OF COARSE AGGREGATES[J]. Journal of the Institution of Civil Engineers, 1945, 24(6):125-133.

[9] Amirkhanian, Serji N, Kaczmarek, Douglas, Burati Jr, James L. EFFECTS OF LOS ANGELES ABRASION TEST VALUES ON THE STRENGTHS OF LABORATORY-PREPARED MARSHALL SPECIMENS[M]. 1991.

[10] C Sensogut¹ , Duzyol S , I Cinar² . Evaluation of Resistance to Los Angeles Abrasion and Physical Factors with Grindability Properties of Some Aggregate Materials[J]. 2017.

[11] Li C , Ashlock J C , White D J , et al. Gyratory abrasion with 2D image analysis test method for evaluation of mechanical degradation and changes in morphology and shear strength of compacted granular materials[J]. Construction & Building Materials, 2017, 152(oct.15):547-557.

[12] Yang, Jian-hong , Fang, Huai-ying. Research into different methods for measuring the particle-size distribution of aggregates: An experimental comparison[J]. Construction and Building Materials, 2019,221(OCT.10):469-478

[13] M, Shabbir, Hossain, et al. Results of Micro-Deval Test for Coarse Aggregates from Virginia Sources:[J]. Transportation Research Record, 2018.

[14] Ioannou I , Fournari R , Petrou M F . Testing the soundness of aggregates using different methodologies[J]. Construction and Building Materials, 2013, 40(Mar.):604-610.

[15] Kline SW, Phiukhao W, Griffin ML, Miller JW. Evaluation of the sodium sulfate soundness test for qualifying dolomites of Northern Arkansas for construction aggregate. In: Nelson RS, DeChurch DA, editors. Proceedings of the 40th forum on the geology of industrial minerals, Indiana Geological Survey; 2007,(Occasional Paper 67).

[16] Forster SW. Soundness, deleterious substances and coatings. In: Lamond JF, Pielert JH editors. Significance of tests and properties of concrete and concretemaking materials. ASTM STP 169D: Pennsylvania; 2006, p. 355–364

[17] Gregory S. Williamson. Investigation of Testing Methods to Determine Long-Term Durability of Wisconsin Aggregate Resources Including Natural Materials, Industrial By-Products, and Recycled/Reclaimed Materials[J]. 2005.

[18] Bulevičius, Matas, Petkevičius, Kazys, Žilionienė, Daiva, 等. Testing of Physical-Mechanical Properties of Coarse Aggregate, Used for Producing Asphalt Mixtures, and Analysis of Test Results[J]. vilniaus gedimino technikos universitetas, 2010.

[19] Ajalloeian R , Kamani M . An investigation of the relationship between Los Angeles abrasion loss and rock texture for carbonate aggregates[J]. Bulletin of engineering geology and the environment, 2019, 78(3):1555-1563.

[20] Esfahani M K , Kamani M , Ajalloeian R . An investigation of the general relationships between abrasion resistance of aggregates and rock aggregate properties[J]. Bulletin of engineering geology and the environment, 2019, 78(6):3959-3968.

[21] Brandes H G , Robinson C E . Correlation of Aggregate Test Parameters to Hot Mix Asphalt Pavement Performance in Hawaii[J]. Journal of Transportation Engineering, 2006, 132(1):p.86-95.

[22] Palassi M , Danesh A . Relationships Between Abrasion/Degradation of Aggregate Evaluated from Various Tests and the Effect of Saturation[J]. Rock Mechanics & Rock Engineering, 2016, 49(7):2937-2943.

[23] Liu J , Zhao S , Mullin A . Laboratory assessment of Alaska aggregates using Micro-Deval test[J]. Frontiers of Structural & Civil Engine, 2017, 11(1):27-34.
[24] U.de S. Jayawardena. A Study on The Relationship between Aggregate Impact Values (AIV) and Los Angeles Abrasion Values (LAAV) of Charnockites/Charnockitic Gneisses in Sri Lanka[J]. Engineer: Journal of the Institution of Engineers, 2016.

[25] Rangaraju P R , Edlinski J . Comparative Evaluation of Micro-Deval Abrasion Test with Other Toughness/Abrasion Resistance and Soundness Tests[J]. Journal of materials in civil engineering, 2008, 20(5):p.343-351.

[26] Zhang S , Pei J , Li R , et al. Effect of Coarse Aggregate Composition on Physical and Mechanical Properties[J]. Journal of Materials in Civil Engineering, 2019, 31(10):04019246.

[27] Eriksen, Eyolf. Plotting aggregate degradation results from the Los Angeles test on a triangular diagram: proposal of a new quality ranking for aggregates[J]. Bulletin of Engineering Geology and the Environment, 2015, 74(2):667-671.

[28] Allam L M , Ebrahimpour A . Comparative Analysis of Idaho and Micro-Deval Aggregate Dearadation Test Methods[J]. Journal of Materials in Civil Engineering, 2014, 26(1):198-201.

[29] Kamani M , Ajalloeian R . Evaluation of the mechanical degradation of carbonate aggregate by rock strength tests[J]. Journal of Rock Mechanics & Geotechnical Engineering, 2019, 11(01):125-138.

[30] Lang A , Range P , Fowler D , et al. Prediction of Coarse Aggregate Performance by Micro-Deval and Other Soundness, Strength, and Intrinsic Particle Property Tests[J]. Transportation Research Record: Journal of the Transportation Research Board, 2007, 2026:3-8.

[31] Ugur I , Demirdag S , Yavuz H . Effect of rock properties on the Los Angeles abrasion and impact test characteristics of the aggregates[J]. Materials Charaterization, 2010, 61(1):90-96.

[32] Al-Harthi A A . A field index to determine the strength characteristics of crushed aggregate[J]. Bulletin of Engineering Geology & the Environment, 2001, 60(3):193-200.

[33] Ajalloeian, Rassoul,Kamani, Mojtaba. An investigation of the relationship between Los Angeles abrasion loss and rock texture for carbonate aggregates[J]. Bulletin of engineering geology and the environment,2019,78(3):1555-1563

[34] Kahraman S , Toraman O Y . Predicting Los Angeles abrasion loss of rock aggregates from crushability index[J]. Bulletin of Materials ence, 2008, 31(2):p.173-177.

[35] Sair, KahramanOsman, Gunaydin. Empirical methods to predict the abrasion resistance of rock aggregates[J]. Bulletin of Engineering Geology & the Environment, 2007.

[36] Teymen A . Estimation of Los Angeles abrasion resistance of igneous rocks from mechanical aggregate properties[J]. Bulletin of Engineering Geology & the Environment, 2019, 78(2):837-846.

[37] Nenerplante D . Durability Assessment of Coarse Aggregates for HMA in Maine[J]. coarse aggregates, 2012, 139(2335):29-36.

[38] Lynn T , James R , Wu P , et al. Effect of Aggregate Degradation on Volumetric Properties of Georgia's Hot-Mix Asphalt[J]. Transportation Research Record Journal of the Transportation Research Board, 2007, 1998(1):123-131.

[39] Collins, R, Watson,. Effect of aggregate degradation on specimens compacted by superpave gyratory compactor[J]. Transp Res Rec, 1997.

[40] Mahmoud, Ameri, Reza,et al.. Evaluation the effects of nanoclay on permanent deformation behavior of stone mastic asphalt mixtures[J]. Construction & Building Materials, 2017.

[41] Moavenzadeh, F. and W. H. Geotz. Aggregate Degradation in Bituminous Mixtures. In  Highway Research Record 24, HRB, National Research Council, Washington, D.C., 1963.

[42] Airey G D , Hunter A E , Collop A C . The effect of asphalt mixture gradation and compaction energy on aggregate degradation[J]. Construction and Building Materials, 2008, 22(5):p.972-980.
[43] Gokalp I, Uz V E, Saltan M. Testing the abrasion resistance of aggregates including by-products by using Micro Deval apparatus with different standard test methods[J]. Construction and Building Materials, 2016, 123(oct.1):1-7.