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Asphalt Materials Research Program

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Abstract

Low-quality mineral aggregates can potentially lead to production, construction, and long-term performance-related problems in asphalt concrete pavements. Therefore, effective qualification criteria for mineral aggregates are paramount. This study was performed to investigate the effectiveness of the Los Angeles abrasion (LAA) test to assess the abrasion resistance of coarse aggregates commonly used in airfield asphalt paving. The LAA test acceptance criteria currently specified by state departments of transportation were examined and compared to the current Department of Defense criterion. Additionally, recent experiences during a forensic evaluation to identify potential sources of excessive presence of foreign object debris on an airfield runway are also briefly discussed in this report. The LAA test and associated acceptance criterion in Unified Facilities Guide Specification (UFGS) 32 12 15.13 were evaluated by testing 24 aggregate sources from various US locations. Also, the Micro-Deval abrasion test was performed as a surrogate abrasion resistance test. Sufficient evidence was not found to suggest adjustments to current LAA test criterion or to recommend the use of an alternative abrasion test. The current UFGS specifications should be improved to provide a more thorough aggregate testing protocol and detailed guidelines regarding aggregate sampling and testing frequency during design and construction of asphalt pavements.

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Preface

This study was conducted for the Air Force Civil Engineer Center (AFCEC) under Project No. 500845, Task No. 79J405, AFCEC Asphalt Materials Research Program. The AFCEC technical monitor was Dr. Craig Rutland. Mr. Jeb S. Tingle, Senior Scientific Technical Manager (SSTM), was the ERDC program manager.

The work was performed by the Airfields and Pavements Branch (GMA) of the Engineering Systems Division (GM), US Army Engineer Research and Development Center, Geotechnical and Structures Laboratory (ERDC-GSL). At the time of publication, Ms. Anna M. Jordan was chief, GMA; Mr. Justin S. Strickler was chief, GM; and Ms. Pamela G. Kinnebrew was the technical director for Military Engineering. The deputy director of ERDC-GSL was Mr. Charles W. Ertle II, and the director was Mr. Bartley P. Durst.

COL Christian Patterson was the commander of ERDC, and Dr. David W. Pittman was the director.

1 Introduction

1.1 Background

Often asphalt concrete distresses such as permanent deformation, stripping (loss of adhesion between aggregate and asphalt binder in the presence of moisture), surface disintegration, and surface frictional resistance can be attributed to low-quality mineral aggregates (Kandhal et al. 1997). Given that mineral aggregates constitute approximately 95% of the mass of asphalt concrete, the quality of the aggregates is critical to ensure that asphalt pavement exhibits satisfactory in-service performance. Mineral aggregates used in pavement construction should be adequately durable to resist crushing, abrasion, and degradation due to the forces exerted on the individual aggregate particles and aggregate skeleton during construction and under traffic. Additionally, aggregates must be adequately sound to withstand the adverse effects of weather. Therefore, trustworthy performance test methods for aggregate evaluation and selection are central to ensuring durable and sound aggregates sources are specified for asphalt pavement construction.

The US DoD currently uses the Los Angeles abrasion (LAA) and magnesium sulfate soundness (MSS) tests as the main performance-related test methods to evaluate the abrasion and soundness, respectively, of mineral aggregates. Recently, excessive foreign object debris (FOD) was observed immediately after the completion of two airfield pavement construction projects. The excessive FOD was preliminarily attributed to potential disintegration of soft mineral aggregates, which subsequently raised questions regarding the validity of the LAA test and the associated acceptance criterion to discriminate the quality of mineral aggregates used in asphalt concrete for airfield pavements. Consequently, the DoD recognized a need to verify current requirements for mineral aggregates in asphalt concrete, specifically the validity of the acceptance limit for the LAA test. By improving the quality of pavement constituents, such as the mineral aggregates, the generation of FOD from degradation and breaking of mineral aggregates can be minimized during construction and operations on airfield asphalt pavements. This report presents an evaluation of the acceptance criterion currently specified for the LAA test under Unified Facilities Guide Specifications (UFGS) 32 12 15 *Asphalt Paving for Airfields* (USACE 2013).

1.2 Objective

The foremost objective of this study was to verify the current acceptance limit for the LAA test to ensure acceptable quality of mineral aggregates used to produce asphalt concrete for airfield pavements, which should contribute to minimizing FOD problems from aggregate-related pavement degradation. The research team accomplished the following technical objectives to complete this study:

- Reviewed existing specifications from state departments of transportation (DOTs) to identify potential recommendations to improve UFGS specifications with respect to selection and quality control of aggregate sources and properties
- Evaluated a representative number of coarse aggregates of different types and sources with the LAA test
- Investigated the potential use of an alternative aggregate abrasion test such as the Micro-Deval abrasion (MDA) test method

1.3 Approach

This study assesses the effectiveness of the LAA test in assessing the abrasion resistance of coarse aggregates commonly used in airfield asphalt paving. First, the current LAA test acceptance criteria specified by state departments of transportation were examined and compared to the criterion used by the DoD. Additionally, the overall results from a forensic evaluation conducted at Columbus Air Force Base (CAFB) to identify potential sources of excessive presence of foreign object debris on an airfield runway were also documented in this study. The research team collected aggregate samples from 24 different sources to conduct an extensive experimental evaluation of the LAA test and corresponding acceptance limit. As an alternative abrasion resistance test, the Micro-Deval abrasion test was also performed to compare its performance to that of the LAA test. The research plan for this study was designed to collect enough information that could potentially lead to refinements to the LAA test and acceptance threshold.

1.4 Outline of Chapters

Chapter 2 consists of a background section that discusses the importance of mineral aggregates in asphalt concrete, the framework of existing specifications for aggregate selection, and the use of aggregate tests such as the LAA and MDA tests. Chapter 3 describes the methodology followed to accomplish the goal of this study. Chapter 4 provides an overall review of current specifications used by state DOTs and the DoD for aggregate selection for asphalt concrete. Chapter 5 highlights the findings from a recently performed forensic evaluation of an airfield pavement with potential aggregate-related pavement distresses. Chapter 6 discusses the laboratory characterization of aggregates using the LAA test. Chapter 7 briefly examines the use of the MDA test as an alternative aggregate test method. Chapter 8 presents conclusions and recommendations from this study.

2 Literature Review

2.1 Alternative Test Methods to Measure Abrasion Resistance

Several studies have focused on improving the effectiveness of the LAA test to determine the abrasion-related quality of aggregates (Larson et al. 1971; Mohajerani et al. 2017; Umar et al. 2020). However, the widespread challenge of using the LAA test is primarily its lack of correlation with the field performance of aggregates, which was not addressed in these research efforts. However, several studies have been conducted to evaluate the MDA test as an alternative to the LAA test (Cooley and James 2003; Cuelho et al. 2007; Lynn et al., 2007; Ugur et al. 2010; Dias Filho et al. 2015; Palassi and Danesh 2016; Liu et al. 2017; Wu et al. 2018).

The MDA test was developed in France during the 1960s and was adapted from the Deval test originally developed in the early 1900s, which is discussed further in Richard and Scarlett (1997). More recently, Cooley and James (2003) documented the use of the MDA test by testing 72 aggregate sources from eight southeastern states. They reported that the MDA test had mixed results categorizing aggregate sources in relation to the performance histories provided by the respective states. A poor relationship between the LAA and MDA was also reported in this study. Cuelho et al. (2007) also evaluated the effectiveness of the MDA test apart from other aggregate tests (including LAA and MSS tests). They recommended that a maximum percent loss of 18% be used for the MDA test results. It was also observed that the MDA, LAA, and MSS tests produced unique values of percent loss for the 32 different aggregates tested in this study; and, thus, the values were normalized to examine potential correlations. The MDA and MSS tests provided a better correlation. Liu et al. (2017) recently evaluated 16 aggregate sources from Alaska by using different aggregate tests including the MDA test. The MDA test was identified as more feasible and reproducible among the different aggregate tests. Additionally, the MDA test yielded consistent results to discriminate the abrasion resistance of the aggregate sources. The MDA test also exhibited a good correlation to the Washington degradation test, which was routinely used in Alaska to assess aggregate durability properties.

The LAA and MDA tests may not necessarily measure aggregate deterioration through a similar testing mechanism, and insufficient evidence is available to justify the replacement of the LAA test by the MDA test for assessing the premature breakdown of mineral aggregates. Similarly, the LAA test has been compared to the aggregate crushing value (ACV) and aggregate impact value (AIV) test methods (Wu et al. 1998; Alvarado et al. 2007; Ugur et al. 2010; Jethro et al. 2014; Reyna et al. 2020). Although these test methods have exhibited satisfactory correlations among each other, the use of the ACV and AIV test methods has been limited in the US.

2.2 Role of Mineral Aggregates in Asphalt Concrete

Asphalt concrete, composed mainly of mineral aggregates and asphalt binder, is widely used in pavement construction. Since the mineral aggregates constitute approximately 95% by mass of an asphalt concrete mixture, aggregate quality has a meaningful effect on the performance of the asphalt pavement. Overall, the aggregate provides an internal structure within an asphalt concrete layer that distributes the traffic load through the aggregate particle contact points (Coenen 2011). Aggregates of higher quality can potentially maximize the stability of this internal structure, which should result in better pavement performance in terms of rutting and permanent deformation (Shashidhar et al. 2000). However, asphalt pavement distresses—such as stripping, surface disintegration, and lack of adequate surface frictional resistance—can be also directly traced to the selection of mineral aggregates during the design process (Kandhal and Parker 1998). Therefore, the selection of aggregates is important to achieve the desired pavement performance.

Aggregate properties are classified into two general categories: consensus properties and source properties. Consensus properties—such as shape, texture, and angularity of aggregates—can be controlled by adopting different production processes, while the aggregate source properties—like hardness, toughness, and soundness—are inherent characteristics related to the source of the aggregate particles, mineral constituents, and geological formations. Studies have shown that aggregate properties play a meaningful role in the quality and performance of an asphalt concrete including aggregate skeleton integrity (Wu et al. 1998; Chowdhury et al. 2001; Singh et al. 2013), permanent deformation (Pan et al. 2006; Huang et al. 2009; Singh et al. 2016; Dulaimi et al. 2017), stiffness and resilient modulus (Monismith 1970; Pan et al. 2005; Bennert 2009), and moisture susceptibility (Hicks 1991; Kakade et al. 2017).

Aggregates used in pavement construction must be resistant to degradation. Aggregate degradation can routinely occur during the aggregate production process (stockpiling, handling, and mixing), and pavement construction (hauling, laydown, and compaction). Tough aggregates are also desirable for pavement construction to minimize variations in aggregate properties during the production and construction processes and ensure that the asphalt mixture in the pavement exhibits properties as close as possible to the design. Moreover, the use of tough, abrasion-resistant aggregates is also important to counteract the abrading and grinding actions of heavy traffic loads. Although an asphalt binder film coats the aggregates in an asphalt mixture, aggregates are often exposed to weathering events (e.g., wetting and drying; freezing and thawing) when they break during construction or when the asphalt film is eventually worn off by traffic. Therefore, aggregates must be also sound and resistant to weathering to minimize disintegration, stripping, and raveling of the asphalt concrete layer. Additionally, the properties of aggregates play an important role on the frictional resistance of the asphalt concrete layer, which is driven by the pavement surface texture and polishing resistance of the aggregates (Khasawneh 2008).

2.3 Existing Specifications for Selection of Aggregates

It is clear from the literature that quality aggregates are one of the primary factors contributing to acceptable long-term performance of asphalt pavements. To maximize aggregate quality in asphalt concrete, state DOTs have developed and implemented thorough specifications for selection of aggregate. The majority of existing specifications call for determining the consensus properties of aggregates, including

- the aggregate gradation and size by sieve analysis per American Society for Testing and Materials (ASTM) C136 (2020c) or American Association of State Highway and Transportation Officials (AASHTO) T 27 (2022b),
- uncompacted void content of fine aggregates per ASTM C1252 (2017c) or AASHTO T 304 (2017),
- percentage of fractured particles in coarse aggregates per ASTM D5821 (2017a),
- flat and elongated particles in coarse aggregates per ASTM D4791 (2019),
- methylene blue test for fine aggregate per ASTM C1777 (2020a), and

- sand equivalent value of fine aggregates per ASTM D2419 (2022) or AASHTO T 176 (2022a).

Additionally, two aggregate tests—the LAA and MSS tests—are commonly specified by DOTs to evaluate the source properties of aggregates used in asphalt concrete. The LAA and MSS tests are used to determine the toughness and durability of aggregates, respectively. However, these aggregate tests' criteria were developed based on limited experience on field performance of aggregates (Kandhal et al. 1997).

The DoD follows UFGS 32 12 15 (USACE 2013) for designing and paving bituminous intermediate and wearing courses for airfield pavements. The selection of the aggregate sources, specifically coarse aggregates, for asphalt concrete is completed by using the LAA and MSS tests. The LAA and MSS test methods are thoroughly described in ASTM C131 (2020b) and ASTM C88 (2018) specifications, respectively. Although the framework of DoD's specifications is very similar to those followed by DOTs for designing and paving asphalt concrete, the DoD engages in pavement construction projects that can be located anywhere within the US and around the world. This unique condition increases the need to have thorough specifications to encompass the wide range of constituent materials that may be encountered. More specifically to the posed topic in this study, DoD specifications must ensure that acceptable quality aggregate sources are selected during airfield pavement construction to ensure the quality of the final product.

Recently, excessive presence of loose particles (also known as FOD) was observed soon after the completion of two airfield pavement construction projects. Engineers at Redstone Arsenal, near Huntsville, Alabama, noticed many surface voids (identified at the time as raveling or "pop-outs") and observed numerous loose soft aggregates on the asphalt concrete surface layer of a taxiway pavement. Similarly, CAFB near Meridian, Mississippi, reported the presence of excessive loose pavement particles on the airfield runway, which were potentially generated by using underperforming aggregates, as well as the misapplication of mix design target values during the design and production of the asphalt concrete. Engineers surmised that the coarse aggregates were not properly coated due to low asphalt content in the asphalt mixtures, which resulted in premature disintegration. Nonetheless, the excessive FOD was preliminarily attributed to issues due to quality of the mineral aggregates, which subsequently raised questions regarding the capability of current DoD specifications to discriminate between adequately and poorly performing mineral aggregates. Further information related to this forensic evaluation is provided in Chapter 5.

2.4 The Los Angeles Abrasion (LAA) Test as an Aggregate Quality Test

The LAA test was developed in 1916 to improve the characterization of aggregates, specifically the durability of the aggregates in terms of degradation potential. Since the adoption of the LAA test, disagreement has arisen regarding the effectiveness of the LAA test to assess the degradation potential of aggregates. Woolf (1937) and Hatt (1938) reported that a relationship exists between the LAA test results and the degradation under field compaction and service records of aggregates, while Goode and Owings (1961) and Lappalainen (1987) noted that the LAA test results could be misleading. After forensic evaluation of road failures, Wylde (1976) commented that in order to improve the applicability of the aggregate test results, the results of a range of aggregate test methods—including the LAA test—should be interpreted in the light of experience with the aggregate in service records. Later, Kandhal et al. (1997) reiterated that many of the existing aggregate tests and acceptance criteria, including the LAA test, were mainly developed based on limited understanding of the field performance of the aggregates. Nonetheless, the LAA test has been considered as a customary quality test for aggregates, given the constant demand for high-quality aggregates for road construction (Amirkhanian et al. 1991). Woolf (1937) reported the following percentage of wear as suitable to control the quality of coarse aggregates: concrete 50%, bituminous surfacing 40%, and surface treatment 40%. Through a national survey, Amirkhanian et al. (1991) confirmed that most of the US state highway agencies use the LAA test with an acceptable limit of 40%.

National Cooperative Highway Research Program (NCHRP) Project 9-35, *Aggregate Properties and Their Relationship to the Performance of Superpave-Designed HMA: A Critical Review* (Prowell et al. 2005), focused on reviewing existing and ongoing research dealing with the development, evaluation, and validation of the Superpave criteria for aggregate selection. No relationship was found between the LAA test results and the long-term wear of asphalt pavement surfaces from this extensive research. Brandes and Robinson (2006) conducted an experimental evaluation of aggregate tests to delineate potential correlations with pavement performance. The LAA test yielded weak correlation with pavement performance (R = 0.33). They concluded that aggregate toughness, as measured by the LAA test, may not be the most important property responsible for good pavement performance. Lynn et al. (2007), after evaluating the characteristics of 22 asphalt mix design variations during production and construction processes, determined that plant mixing and field compaction activities resulted in aggregate degradation. However, the degradation potential of aggregates could not be directly correlated with aggregate toughness as measured by the LAA. Bartley et al. (2010) also investigated the degradation of coarse aggregates that are commonly used in stone matrix asphalt and open-graded asphalt mixtures. They observed that most of the properties determined by using the aggregate source tests, including the LAA test, had no relevance in terms of the ability of the aggregate to withstand the construction process.

2.5 Summary of Literature Review

The literature consensus is that aggregate quality has a meaningful effect on the performance of asphalt pavement. The selection of acceptable-quality aggregate can be achieved only by specifying reliable and representative acceptance test criteria. The acceptance criterion for the LAA test method was established several decades ago and reflects merely the perceived performance of aggregates on asphalt pavements. Furthermore, we confirmed that most transportation agencies still use an acceptance criterion of 40% for the LAA test even though an acceptable correlation has not been reported between the performance of the aggregates in the field and the LAA test results. However, the DoD engages in paving projects that can be located anywhere within the US and around the world. This unique condition increases the need to have comprehensive specifications to encompass the wide range of indigenous pavement materials. Thus, the adoption of a representative qualification criterion for mineral aggregates is paramount to ensure acceptable-quality pavement materials are used in airfield asphalt pavements.

3 Methodology

3.1 Description of LAA Test Procedure

The LAA test has been widely used to measure the toughness and durability of mineral aggregates resulting from a combination of abrasion, impact, and grinding actions. The LAA test was conducted in accordance with ASTM C131, *Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine* (2020b).

Figure 1 depicts the LAA device and test setup. The LAA test is conducted in a hollow steel cylinder that rotates at a speed of 30 to 33 rpm* for 500 revolutions. A charge consisting of steel spheres is used to induce damage to the aggregates via abrasion and impact. The number of steel spheres depends on the grading of the aggregate test sample. Table 1 summarizes the grading requirements to prepare aggregate samples for the LAA test as well as the number of steel spheres associated with each grading. After the prescribed number of revolutions is met, the charge is removed from the LAA machine, and the material is discharged for further processing. A preliminary separation of the tested aggregates is performed with a sieve coarser than the No. 12 (1.70 mm) sieve. The material retained on the No. 12 (1.70 mm) sieve is washed and oven dried at 230°F ± 9°F (110°C ± 5°C) to a constant mass.

The percent loss of material, which is the main output parameter from the LAA test, is calculated using Equation (1).

$$Percent\ Loss = \frac{(C-Y)}{C} \times 100, \tag{1}$$

where

C = the mass of original test sample in grams, and
Y = the final mass of the test sample in grams.

The percent loss of material obtained from the LAA test provides an indication of the abrasion resistance of the aggregate. A low LAA value

* For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

indicates that the material has high abrasion resistance. Conversely, a high LAA value indicates that the aggregate has low abrasion resistance.

Figure 1. Los Angeles abrasion (LAA) test.

(a) LAA test device *(b) Hollow steel cylinder*

(c) Revolutions counter *(d) Charge of steel spheres*

Table 1. Grading of aggregate test samples for LAA test.

Sieve Size		Mass of Indicated Sizes, g			
		Grading			
Passing	Retained On	A	B	C	D
1 ½ in. (37.5 mm)	1 in. (25 mm)	1,250 ± 25	—	—	—
1 in. (25 mm)	¾ in. (19 mm)	1,250 ± 25	—	—	—
¾ in. (19 mm)	½ in. (12.5 mm)	1,250 ± 10	2,500 ± 10	—	—
½ in. (12.5 mm)	3/8 in. (9.5 mm)	1,250 ± 10	2,500 ± 10	—	—
3/8 in. (9.5 mm)	¼ in. (6.3 mm)	—	—	2,500 ± 10	—
¼ in. (6.3 mm)	No. 4 (4.75 mm)	—	—	2,500 ± 10	—
No. 4 (4.75 mm)	No. 8 (2.36 mm)	—	—	—	5,000 ± 10
Total		5,000 ± 10			
Number of Spheres		12	11	8	6
Mass of Charge, g		5,000 ± 25	4,580 ± 25	3,330 ± 20	2,500 ± 15

In this evaluation, test sample gradings B, C, and D were produced and tested for the aggregate sources when enough material was generated during sieving and processing of the raw aggregates. Three replicate test samples were performed for every aggregate source and corresponding LAA test sample grade.

3.2 Alternative Aggregate Test for Abrasion Resistance

The MDA is a popular test method used to measure the abrasion resistance of aggregates. The MDA test measures the quality of aggregates when subjected to a combination of abrasion and grinding with steel spheres in the presence of water. The MDA test is conducted in accordance with ASTM C6928, *Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus* (2017b).

Figure 2 depicts the MDA device and test setup. The MDA test is conducted in a stainless-steel jar with an approximately 5 L capacity that rotates inside a rolling mill capable of running at 100 ± 5 rpm (see Figure 2*a*). An abrasive charge consisting of steel spheres is used to induce damage via abrasion and grinding to the aggregates during the MDA test. Each jar requires an abrasive charge of 5,000 ± 5 g of steel spheres. Table 2 summarizes the grading requirements to prepare aggregate samples for the MDA test as well as the number of revolutions or time of testing associated with each grading. The aggregate samples need to be soaked in approximately 2 L of water for not less than 1 hr before testing. The jar, aggregate, water, and abrasive charge are revolved in the rolling mill for the specified testing time. On completion of the testing time, the abrasive charge is removed, and the aggregate sample is washed and oven dried at 230°F ± 9°F (110°C ± 5°C) to a constant mass. The loss is the amount of material passing the 1.18 mm sieve expressed as a percent by mass of the original sample weight. The percent loss of material can be calculated using Equation (2).

$$Percent\ Loss = \frac{(C-Y)}{C} \times 100, \tag{2}$$

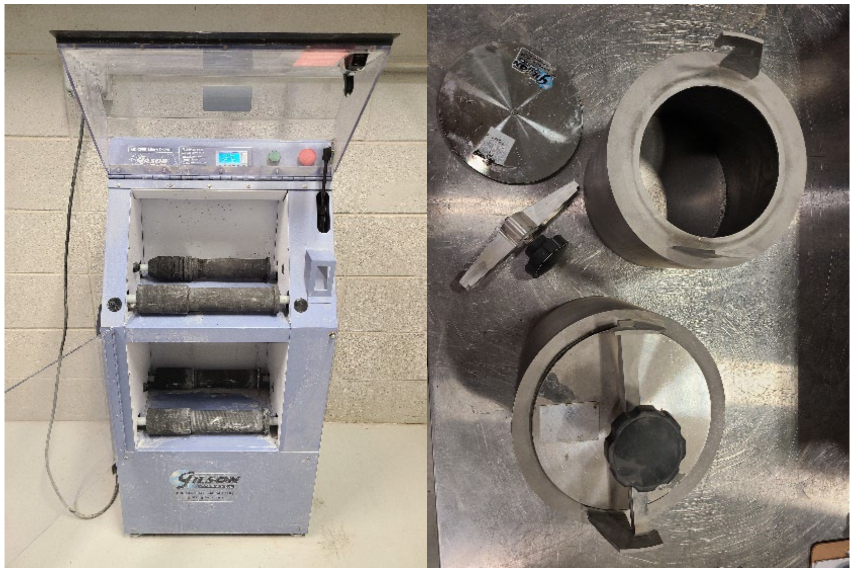
where

C = the mass of original test sample in grams, and
Y = the final mass of the test sample in grams.

Table 2. Grading of aggregate test samples for MDA test.

Sieve Size		Mass of Indicated Sizes, g		
		Sample Grade		
Passing	Retained On	19.0 mm	12.5 mm	9.5 mm
¾ in. (19 mm)	5/8 in. (16 mm)	375	—	—
5/8 in. (16 mm)	½ in. (12.5 mm)	375	—	—
½ in. (12.5 mm)	3/8 in. (9.5 mm)	750	750	—
3/8 in. (9.5 mm)	¼ in. (6.3 mm)	—	375	750
¼ in. (6.3 mm)	No. 4 (4.75 mm)	—	375	750
Test counter setup	Revolutions	12,000 ± 100	10,500 ± 100	9,500 ± 100
	Time	120 ± 1 min	105 ± 1 min	95 ± 1 min

Figure 2. Micro-Deval abrasion (MDA) test



(a) MDA test device *(b) Stainless steel jar*

(c) Revolutions/time counter *(d) Charge of steel spheres*

Like the LAA test, the percent loss of material obtained from the MDA test provides an indication of the abrasion resistance of the aggregate. A low MDA value indicates that the material has high abrasion resistance. Conversely, a high MDA value indicates that the aggregate has low abrasion resistance, which relates to poor quality aggregate.

3.3 Aggregate Sources and Types

Aggregates were sampled and shipped from aggregate producers at different locations in the US. Figure 3 illustrates the distribution of the aggregate sources and types included in this evaluation. Twenty-four aggregate sources were sampled for this experimental evaluation of the LAA test.

Figure 3. Distribution of aggregate sources selected for this evaluation.

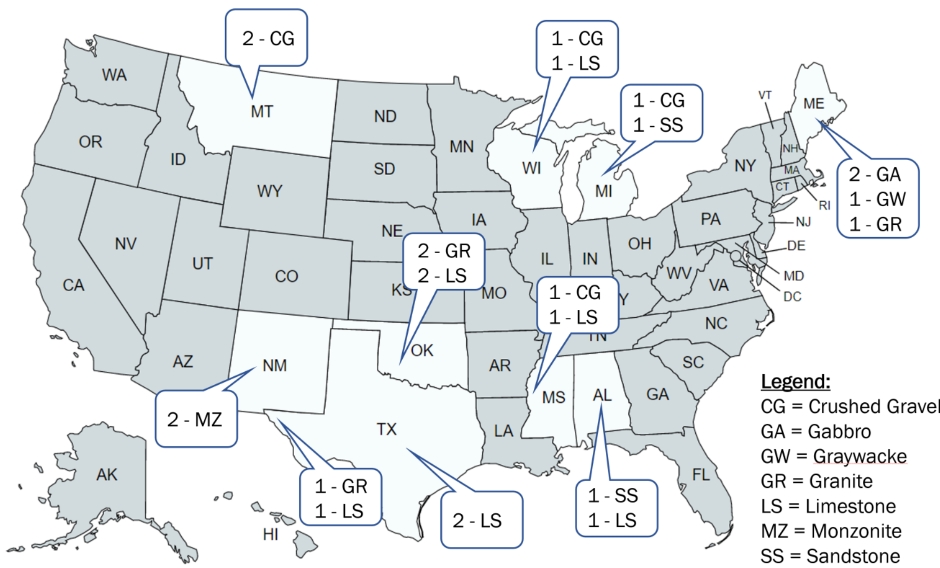


Table 3 summarizes the aggregate sources and types that were tested in this evaluation. The aggregate types included crushed gravel, gabbro, greywacke, granite, limestone, monzonite and sandstone. The aggregates were sampled from nine states. The most recent aggregate gradation for the stockpiles sampled was requested from the selected aggregate suppliers. The percent retained weights for each aggregate size—including ½ in., 3/8 in., No. 4, and No. 8—are presented in

Table 3. With this information, the particle distributions of the aggregate sources were examined to identify the corresponding sample grading for the LAA and MDA tests. Given that some of the aggregate sources generated enough material, the LAA and MDA tests were conducted on more than one sample grading.

Table 3 shows the sample gradings tested for the LAA and MDA tests.

Table 3. Experimental testing matrix and sample grading for LAA and MDA tests.

Aggregate Reference	Aggregate Type	US State	Aggregate Gradation Percent Retained				LAA Grading			MDA Grading	
			1/2 in.	3/8 in.	No. 4	No. 8	B	C	D	12.5 mm	9.5 mm
CG1	Crushed Gravel	MS	14	13	30	17	√	√	√	√	√
CG2	Crushed Gravel	MT	46	32	19	1	√	—	—	√	√
CG3	Crushed Gravel	MT	46	32	19	1	√	—	—	√	√
CG4	Crushed Gravel	WI	44	43	9	0	√	—	—	√	√
CG5	Crushed Gravel	MI	58	33	7	0	√	—	—	—	√
GA1	Gabbro	ME	70	22	3	0		√	—	—	—
GA2	Gabbro	ME	0	3	80	13	√	—	—	—	√
GR1	Granite	TX	27	28	40	1	√	—	—	√	—
GR2	Granite	OK	19	24	43	8	—	√		√	√
GR3	Granite	OK	32	31	35	1	√	—	—	—	—
GR4	Granite	ME	3	47	39	5	—	√	—	—	—
GW1	Greywacke	ME	74	15	3	0	√	—	—	—	√
LS1	Limestone	MS	12	14	36	18	√	√	√	√	√
LS2	Limestone	AL	5	19	58	16	√	√	√	√	√
LS3	Limestone	TX	0	21	60	12	—	√	√	√	√
LS4	Limestone	TX	1	7	49	36	—	√	—	√	√
LS5	Limestone	OK	45	42	13	0	√	—	—	√	√
LS6	Limestone	TX	24	17	37	17	√	√	√	√	√
LS7	Limestone	OK	1	18	69	10	—	√	√	√	—
LS8	Limestone	WI	32	27	36	3	√	—	—	—	—
MZ1	Monzonite	NM	0	4	62	30	—	√	√	—	√
MZ2	Monzonite	NM	45	47	6	0	√	—	—	—	—
SS1	Sandstone	AL	15	21	47	12	√	√	√	√	√
SS2	Sandstone	MI	50	43	3	0	√	—	—	√	—

Notes: CG = crushed gravel, GA = gabbro, GR = granite, GW = greywacke, LS = limestone, MZ = monzonite, SS = sandstone, LAA = Los Angeles abrasion, MDA = Micro-Deval abrasion, MS = Mississippi, MT = Montana, WI = Wisconsin, MI = Michigan, ME = Maine, TX = Texas, OK = Oklahoma, AL = Alabama, OK = Oklahoma, and NM = New Mexico.

4 Review of Current DoD and Departments of Transportation (DOTs) Specifications

4.1 Unified Facilities Guide Specifications (UFGS) Requirements for Coarse Aggregates in Asphalt Concrete

UFGS 32 12 15.13 (USACE 2013) describes the requirements for designing and paving bituminous intermediate and wearing courses for airfield pavements. This specification provides guidelines to select mineral aggregate sources for asphalt mixtures. In general, subsection 2.2.1 “Coarse Aggregate” calls for coarse aggregates consisting of sound, tough, and durable particles. The selection of the coarse aggregate is performed primarily based on two test methods, the MSS and LAA tests. The MSS and LAA test methods are thoroughly described in ASTM C88 (2018) and ASTM C131 (2020b) specifications, respectively. As such, coarse aggregates must meet the following requirements:

a. The percentage of loss shall not be greater than 40% when tested in accordance with ASTM C131.
b. The sodium sulfate soundness loss shall not exceed 12%, or the magnesium sulfate soundness loss shall not exceed 18% after five cycles when tested in accordance with ASTM C88.
c. Additional requirements are also provided for fractured faces, particle shape, slag related material, and clay lumps and friable particles for coarse aggregates.

In addition, the specifications provide the following note that can be considered when selecting coarse aggregates when applicable to specific construction projects:

> The requirement for sulfate soundness (requirement b., above) may be deleted in climates where freeze-thaw does not occur. However, in those areas where freeze-thaw does not occur, requirement b. must remain if experience has shown that this test separates good performing aggregates from bad performing aggregates. Retain this requirement for all Navy projects. Percentage of Wear (ASTM C131) must not exceed 40%. Aggregates with a higher percentage of wear may be specified, provided a satisfactory

record under similar conditions of service and
exposure has been demonstrated.

As it pertains to this report, the LAA test is performed to determine the quality of aggregate sources in terms of abrasion resistance. An acceptance criterion of percentage loss less than or equal to 40% is currently specified to discriminate between adequately and poorly performing aggregates. An assessment of this acceptance limit is required to investigate the validity of the LAA test as an aggregate quality indicator. In addition, a comparison of acceptance limits from state DOTs can help to assess how representative DoD specifications are in terms of using the LAA test for aggregate evaluation and selection.

4.2 Comparison of DoD's and DOTs' Acceptance Limits for LAA Test

The acceptance limits currently used by US DOTs for the LAA test were collected for further analysis and compared to current DoD specifications. Figure 4 presents the distribution of LAA test acceptance limits. This data sample includes the LAA test acceptance limits from the 50 states. Approximately 40% of the DOTs specified a current acceptance limit of 40% for the LAA test. Fewer than 20% of the DOTs have stricter acceptance limits for the LAA test, while the rest of the DOTs (close to 40%) have acceptance limits for the LAA test that are greater than 40%.

In comparison to the acceptance limit used by most DOTs, the current acceptance limit of 40% from the DoD and the Federal Aviation Administration (FAA), illustrated by the gray shaded area in Figure 4, is typical for the LAA test. In general, the current LAA test acceptance limit could be considered representative of DOTs' current practices with limited exceptions for those state DOTs that have adopted stricter acceptance limits. The acceptance limits associated with each state DOT are reflected in Figure 5. The state DOTs were color-coded based on the acceptance limit for the LAA test. State DOTs in green currently use an acceptance limit of 40% for the LAA test. State DOTs with LAA acceptance limits less than 40% are in light green. If the state DOT is in light yellow, the LAA acceptance limit is greater than 40%. A few state DOTs have multiple acceptance limits for the LAA test depending on the specific use of the aggregate (e.g., different aggregate types, traffic levels, or mix design type). For example, Kentucky DOT specifies three LAA acceptance limits of 60%, 50%, and 40%, which are used to examine the abrasion resistance of slag, sandstone, and all other aggregate types, respectively. Similarly, the New York DOT requires an LAA value of 45% or less for marble and granite aggregates, while an LAA value of 35% is specified for all other aggregate types. Moreover, Utah DOT considers the number of gyrations used for the mix design to specify the LAA acceptance limit while Montana DOT changes the LAA acceptance limit when designing asphalt concrete mixtures with a 9.5 mm nominal maximum aggregate size. Figure 4 shows the state DOTs with multiple criteria.

Figure 4. Analysis of departments of transportation (DOTs) acceptance limits for LAA test.

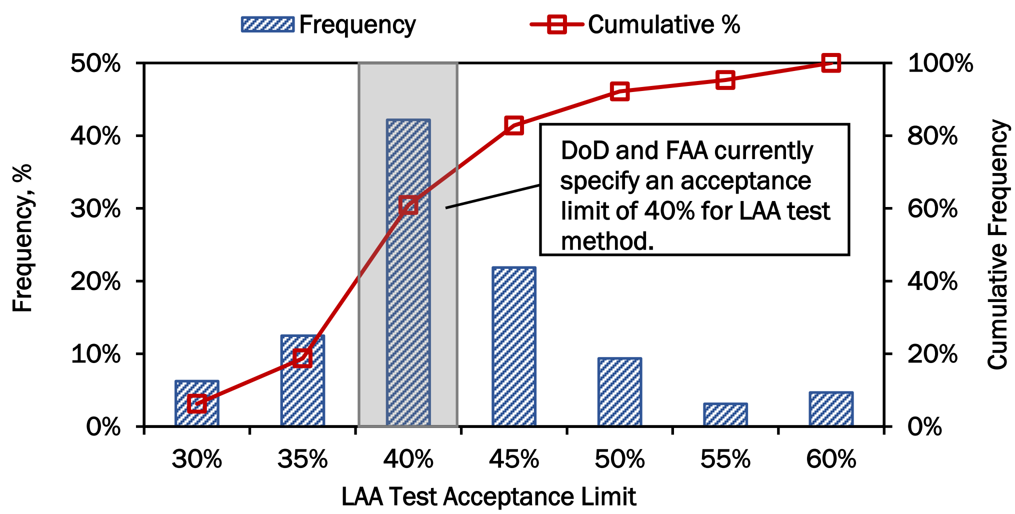
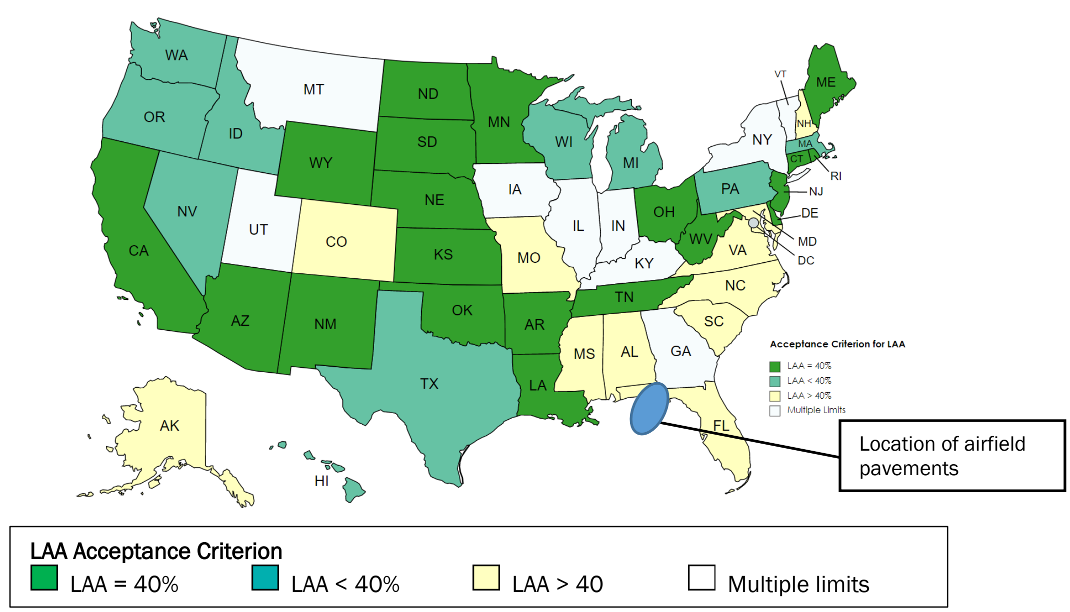
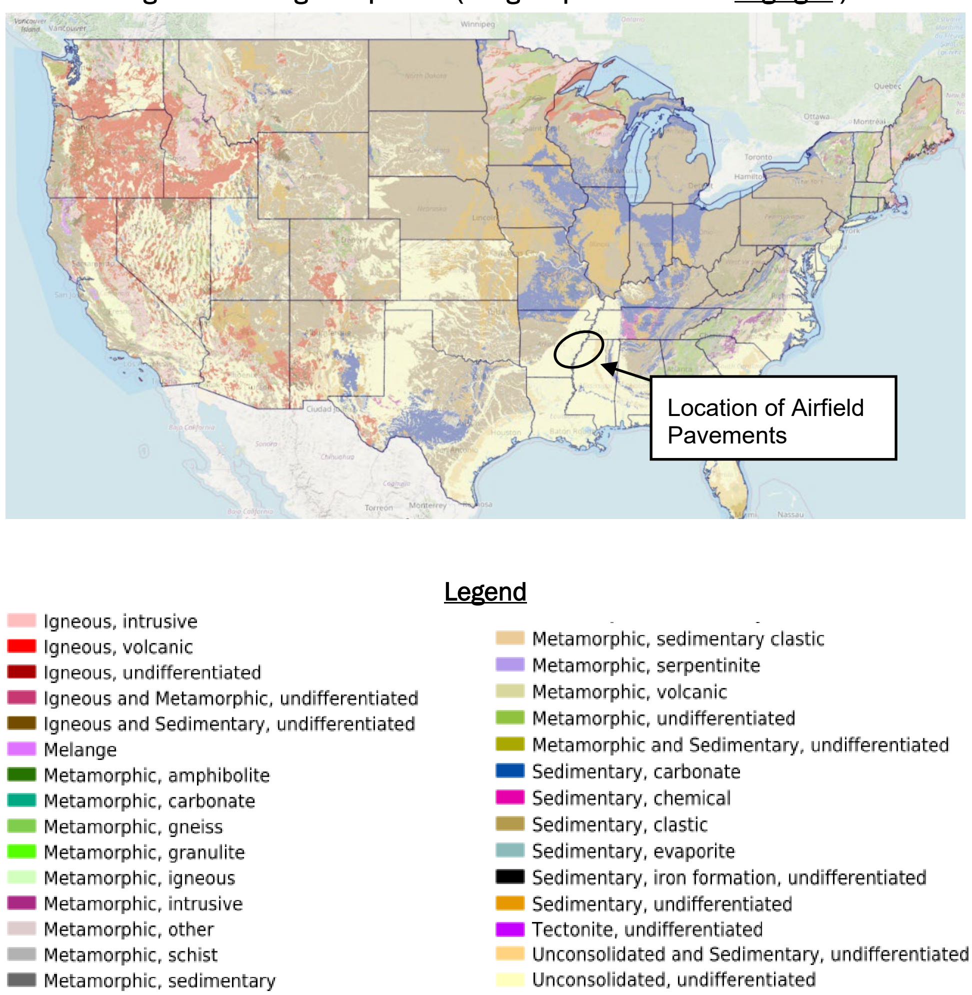


Figure 5. Distribution of LAA test acceptance limit per state DOT.



For reference, the airfield pavements that experienced excessive FOD or premature disintegration of asphalt concrete material are marked on the map in Figure 5. The state DOTs of Alabama and Mississippi, in which these airfield pavements are located, currently specify acceptance limits of 48% and 45%, respectively, for the LAA test. This could be interpreted as a lack of high-quality aggregates for asphalt paving in this region. A geological map of the US is presented in Figure 6. From the geologic map, it can be observed that the area surrounding the airfields of interest consists mainly of alluvial deposits of clay, sand, and gravel. Moreover, the primary mineral aggregates located in this area are mainly sedimentary rocks such as limestone, sandstone, mudstone, and siltstone, which are often perceived as low-quality aggregate types (Szabo et al. 1988).

Figure 6. Geologic map of US (Image reproduced from usgs.gov.)



Regardless, current DoD specifications do not allow the use of an aggregate source with LAA values greater than 40% unless the aggregate sources have previously exhibited a satisfactory record under similar conditions of service. This exception would be applicable only on request from the DoD project engineer responsible for the airfield paving project.

5 Forensic Evaluation of Columbus Air Force Base (CAFB) Runway

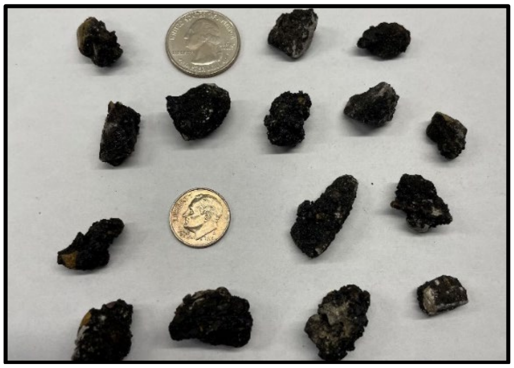
5.1 Overview of Pavement Issues at CAFB

The Air Force Civil Engineer Center (AFCEC) tasked the US Army Engineer Research and Development Center (ERDC) with performing a forensic evaluation of CAFB Runway 13L-31R. This forensic evaluation consisted of investigating an increase in observations of FOD on the asphalt pavement surface.

Runway 13L-31R is an 8,000 ft runway with 1,000 ft concrete overruns; the interior 6,000 ft is asphalt surfaced. The runway was rehabilitated in fall 2018, at which time all 5 in. of existing asphalt pavement were removed and replaced with two 2.5 in. thick lifts of UFGS-32 12 15.13 (USACE 2013) Gradation 2 asphalt mixture using a Performance Grade (PG) 76-22 asphalt binder. The aggregate mixture was composed of 50% limestone, 35% crushed gravel, and 15% sand. The design asphalt content at 75 gyrations was 5.60%. Tensile strength ratio (TSR) was 91.2%, which surpasses the 75% minimum requirement. All mixture design properties and volumetric proportions provided to ERDC were reasonable and in accordance with UFGS-32 12 15.13 (USACE 2013).

Runway inspections noted loose aggregate on the runway surface (Figure 7*a*) and small surface voids (Figure 7*b*). Aggregate particles and surface voids were generally ¼ to ¾ in. in diameter, though some were larger (Figure 7c). Visual inspection revealed on the pavement surface soft aggregate particles that deteriorated easily when probed by a knife, fingernail, or keys (Figure 7*e* and Figure 7*f*). Careful scratching away of these particles left clean voids in the surface that appeared like the other surface voids on the pavement (i.e., as if an entire aggregate had been cleanly removed from the pavement). Several larger surface voids approximately 3 to 4 in. in diameter (as shown in Figure 7*b*) were also observed, but these were not widespread on the pavement surface. ERDC sampled eight pavement cores that contained either visible soft aggregate particles, surface voids, or both for laboratory analysis. Lastly, ERDC inspectors observed medium–severity longitudinal joint cracking, suggesting low joint density (Figure 7*d*).

Figure 7. Photographs from Columbus Air Force Base (CAFB) runway pavement inspection.



(a) FOD collected by CAFB

(b) Typical ¼ to ¾ in. surface void

(c) Large surface void observed by CAFB

(d) Medium severity longitudinal joint crack

(e) Deteriorating soft aggregate particle

(f) Soft aggregate particle removed with knife

The information presented in this report serves only to provide context to the reason behind conducting a research project on the effectiveness of the LAA test for abrasion resistance of mineral aggregates in asphalt concrete. The Memorandum for Record (MFR) developed by Drs. Ben Cox and Sadie Casillas from the Airfields and Pavements Branch of the Engineering Systems Division, Geotechnical and Structures Laboratory (GSL) at ERDC can be accessed upon request to the corresponding authors.

5.2 Analysis of Aggregate Properties during Forensic Evaluation

An obvious issue noted during the field visual inspection was the presence of numerous ¼ to ¾ in. diameter surface voids, which are referred to as pop-outs. This pavement distress was perceived as a potential source of FOD (i.e., an aggregate particle pops out of the pavement and becomes FOD). Numerous deteriorating aggregate particles appearing to be limestone were visible on the surface in addition to the numerous surface voids. Closer investigation revealed these were soft, chalky particles that could be easily scratched with a fingernail. Careful scraping with a pocketknife could etch away and remove an entire soft aggregate particle, with the remaining void appearing identical to other surface voids once dust was blown out. These soft aggregate particles visible on the surface were widespread across the runway and were in various stages of deterioration.

ERDC conducted several test methods and analyses to investigate the properties of the aggregates and identify the potential issues at CAFB runway pavement. ERDC collected asphalt slabs from the runway pavement to extract the mineral aggregates. The extracted aggregates were used to batch aggregate samples to conduct the LAA and MDA tests. For the LAA test, aggregate samples were batched for the gradings C and D. The aggregate samples batched for the MDA test were 12.5 and 9.5 mm. Three aggregate samples were conducted for the LAA test, while only two aggregate samples were tested for the MDA test for each aggregate sample grading. A maximum 40% of mass loss is specified for the LAA test. The MDA test is not currently a part of DoD specifications, so an official acceptance limit is not provided. As a reference in this analysis, the stricter acceptance limit found in the literature was 15%, which is currently used by the Texas DOT. Table 4 reports the LAA and MDA test results of the aggregates extracted from the CAFB runway pavement. Based on the acceptance limit of the LAA test, the average LAA values of 24.3% and 26.8% are satisfactory regardless of the aggregate sample grading. Similarly, the MDA test results were 6.1% and 5.3% for aggregate sample gradings 12.5 and 9.5 mm, respectively. These MDA values are low and could be acceptable if a maximum acceptance limit of 15% were used. From the LAA and MDA tests results, the extracted aggregates from the CAFB runway pavement do not present a low abrasion resistance, which could be a potential cause for premature degradation and disintegration of aggregate particles exposed on the surface of the pavement.

Table 4. LAA and MDA test results from extracted aggregates from CAFB runway pavement.

Test	Grading	Sample Number 1	2	3	Average	Acceptance Criterion
LAA	C	23.9	24.5	24.5	24.3	40%
	D	27.3	27.0	26.1	26.8	
MDA*	12.5	5.8	6.3	–	6.1	Not applicable
	9.5	5.2	5.4	–	5.3	

** The MDA is not currently included in DoD specifications to characterize mineral aggregates.*

The causes of premature aggregate disintegration cannot be traced to the LAA and MDA test results. From the field visual investigation, we observe that the major aggregate-related issues at CAFB runway pavement may be related to the intrusion of poor durability minerals. For example, gypsum, clay lumps, and friable particles were present, as noted by the relatively large holes that were left in the pavement (refer to Figure 8*a*), and an iron pyrite reaction was noted by the rust stains around the pop out (see Figure 8*b*). Thus, it is unclear whether the LAA and MDA tests are sensitive enough to capture the presence of these causes of aggregate-related issues, which may be a relatively small percentage of the overall aggregate source.

Figure 8. Major aggregate-related issues on the CAFB runway pavement.

(a) Intrusion of low-quality aggregate *(b) Presence of iron pyrite*

5.3 Lessons Learned from Forensic Evaluation of CAFB Runway Pavement

The LAA test may be perceived as a test method that can identify aggregate-related issues. However, the type of aggregate-related issues observed at the CAFB runway pavement may not be necessarily picked up by the LAA. In fact, we observed that the extracted aggregates yielded acceptable LAA abrasion values, while it was evident that there was an issue with premature aggregate disintegration at the CAFB runway pavement. Furthermore, the MDA test results also indicated satisfactory abrasion resistance of the extracted aggregates, which means that the MDA test could not identify a potential for premature aggregate disintegration. Again, the testing mechanism of the LAA and MDA tests may not fundamentally identify aggregate-related issues like the ones encountered during the forensic evaluation of the CAFB runway pavement.

While UFGS-32 12 15.13 (USACE 2013) requires aggregate that meets an array of properties, including the ASTM C131 (2020b) LAA test during the design phase, aggregate quality control testing is specified at a frequency of every 20,000 tons during production. The 20,000 ton measurement interval results in testing occurring once or twice during a typical resurfacing project for an airfield pavement. Thus, this testing frequency is not high enough to pinpoint problems that may occur during production. The 20,000 ton testing frequency and requirement to submit results is specified only for specific gravity, fractured faces (gravels), and fine aggregate uncompacted void content. These three tests may not fundamentally identify aggregate-related issues like those observed at the CAFB runway pavement.

The information generated during the forensic evaluation of the CAFB runway pavement highlights the importance of revising current specifications and testing requirements for mineral aggregates used in asphalt concrete. Therefore, the current UFGS-32 12 15 (USACE 2013) should be improved to provide not only a more thorough aggregate testing protocol but also detailed guidelines regarding the sampling and testing frequency of mineral aggregates used in asphalt concrete for airfield paving.

6 Evaluation of LAA Test

6.1 Typical Distribution of LAA Test Results

The 24 aggregate sources sampled during this project were evaluated per the LAA test following the ASTM C131 (2020b) protocol. Referring to Table 1, sample grading B requires an aggregate blend of ½ in. and 3/8 in. material. Grading C calls for an aggregate blend of ¼ in. and No. 4 material to produce the test samples. The grading D sample consists of only No. 8 material. Considering the material required for the aggregate test samples, an LAA grading designation representative of the aggregate distribution was assigned to each aggregate source. The collected aggregate samples were designated a grading of either B or C. These designations were done by considering the nominal maximum aggregate size of the aggregate sources. It should be also mentioned that some of the aggregate sources produced enough material to conduct the LAA test following more than one grading designation. For example, MZ1 aggregate could have been tested using grading C or D, while CG1 aggregate generated enough material to produce grading B and C.

The average LAA value was calculated from triplicate samples tested for each aggregate source. Table 5 summarizes the raw data, and Figure 9 shows the frequency distribution of the LAA test results from the 24 aggregate sources. From the total number of aggregates, 63% of the aggregate sources exhibited average LAA values between 20% and 30%. Only 13% of the aggregate sources yielded average LAA values smaller than 20%, which would be considered the best performing aggregates in terms of abrasion resistance. These aggregates are two crushed gravels and a monzonite aggregate type.

Considering the current acceptance limit of 40% for the LAA test, approximately 17% of the aggregate sources exhibited unacceptable average LAA values (average LAA value greater than 40%). These underperforming aggregate sources correspond to two granites, a gabbro, and a sandstone aggregate.

The LAA test results were further analyzed by grouping the LAA values on box plots based on the LAA test sample grading (e.g., grading B versus grading C). Figure 10 presents the box plots created to compare the overall distribution of LAA values for grading B versus grading C. In this case, both groups had a sample size of 12. It can be noticed that, in general, the aggregate sources with a grading C designation yielded greater LAA values, although both groups exhibited a similar range of LAA values.

Table 5. Summary of LAA test results.

Aggregate Reference	Aggregate Type	LAA Test Results			
		Sample Grading	Average	Standard Deviation	Coefficient of Variation
CG1	Crushed Gravel	B	17%	0%	1%
		C	19%	0%	1%
		D	18%	0%	0%
CG2		B	22%	1%	3%
CG3		B	22%	1%	4%
CG4		B	30%	2%	8%
CG5		B	19%	1%	6%
GA1	Gabbro	B	21%	1%	5%
GA2		C	54%	0%	1%
GR1	Granite	B	47%	1%	2%
GR2		C	35%	9%	27%
GR3		B	20%	1%	4%
GR4		C	47%	2%	4%
GW1	Graywacke	B	23%	1%	2%
LS1	Limestone	B	26%	1%	3%
		C	29%	0%	1%
		D	29%	0%	1%
LS2		B	28%	0%	2%
		C	28%	0%	0%
		D	25%	0%	0%
LS3		C	28%	0%	1%
		D	26%	0%	0%
LS4		C	21%	1%	6%
LS5		B	26%	1%	5%
LS6		B	27%	1%	3%
		C	26%	0%	1%
		D	23%	1%	3%
LS7		C	22%	0%	1%
		D	21%	0%	1%
LS8		B	21%	1%	4%
MZ1	Monzonite	C	32%	5%	15%
		D	31%	3%	11%
MZ2		B	19%	1%	4%

Table 5 (cont.). Summary of LAA test results.

SS1	Sandstone	B	43%	1%	1%
		C	40%	1%	2%
		D	38%	1%	3%
SS2		B	30%	0%	1%

Figure 9. Distribution of typical LAA test results.

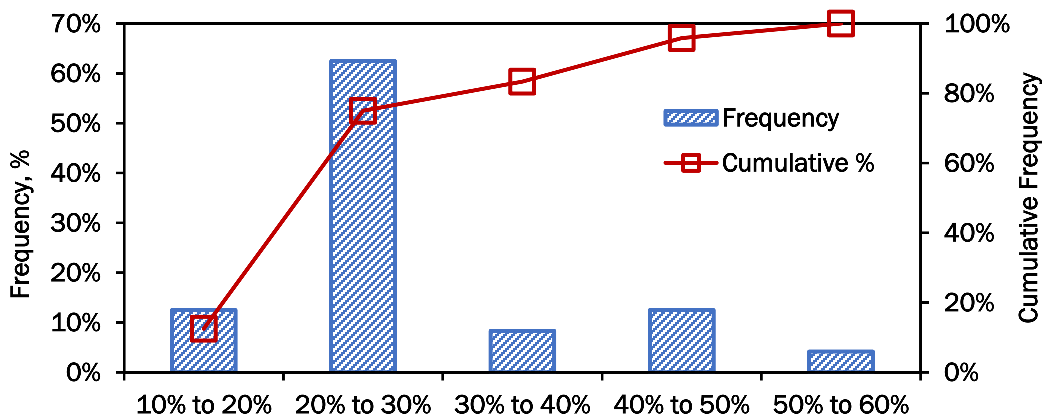
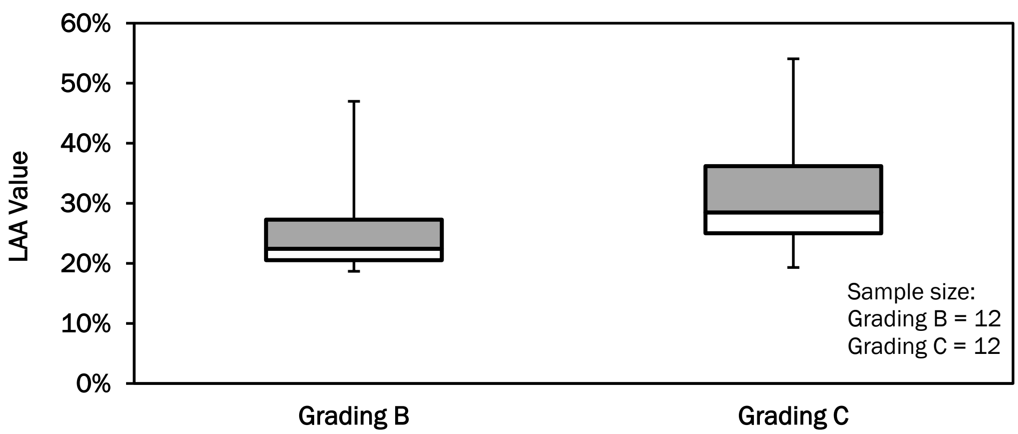


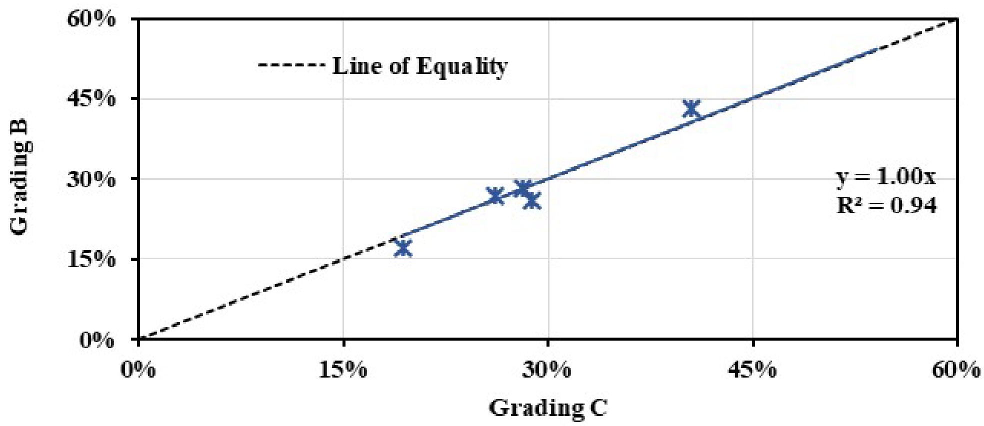
Figure 10. Analysis of LAA values based on sample grading.



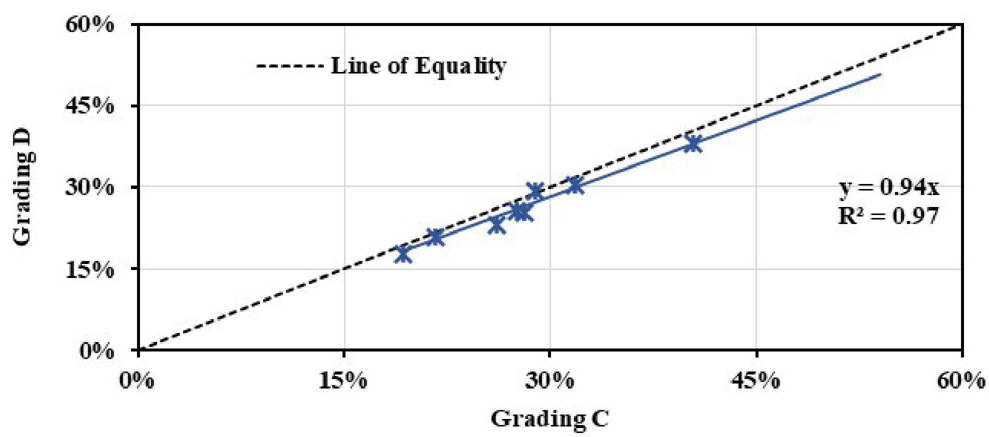
6.2 Impact of LAA Test Sample Grading

To confirm that the reported LAA value would be reliable regardless of the sample grading, LAA tests were performed using different sample grading designations for some of the aggregate sources. As seen in Figure 11, equality plots were used to compare the LAA test results from different sample grading designations batched from the same aggregate source. In general, it was found that the sample grading does not meaningfully influence the discrimination potential of the LAA test. From Figure 11*a*, the comparison of LAA test results between gradings C and B yielded a coefficient of determination (R^2) of 0.94. The linear function fitted through the data points followed an identical pattern to that from the line of equality. Similar observations can be provided from Figure 11*b*, which shows that the LAA test results from gradings C and D are identical. The relation between LAA test results from gradings C and D yielded an R^2 of 0.97, while the slope value of the fitted linear function was 0.94.

Figure 11. Equality plots for relation of LAA test sample grading designations.



(a) Relation of sample grading C versus B



(b) Relation of sample grading C versus D

We note that one aggregate source yielded LAA values of 38%, 40%, and 43% for gradings D, C and B, respectively. This specific aggregate source will be tested following grading C, which will result in a marginal aggregate source (LAA value of 40%). By changing the grading for the test sample, this aggregate source can yield an acceptable LAA test result with grading D and a worse LAA test result if tested with grading B. Although these LAA values are very close to the acceptance criterion of 40%, these results highlight the importance of providing thorough specifications on how to perform the LAA test for aggregate selection.

7 Alternative Abrasion Test Method

7.1 Micro-Deval Abrasion (MDA) Test Results for Typical Coarse Aggregates

Twenty of the aggregate sources were tested with the MDA test. The aggregates sources were assigned a test sample grade (either 12.5 or 9.5 mm). From the 20 aggregate sources, half corresponded to the 12.5 mm sample grade and the other half to the 9.5 mm sample grade. When feasible, both sample grades were tested in the laboratory to investigate any effect on the abrasion resistance of the aggregate sources. Table 6 summarizes the MDA test results collected.

The average MDA value was calculated from triplicate samples tested for each aggregate source and sample grade. Figure 12 shows the frequency distribution of the MDA test results. From the total number of aggregate sources, 42% of the aggregate sources yielded MDA values of between 10% and 15%. Approximately 32% of the aggregate sources yielded MDA values greater than 15%. The MDA test results of about 26% of the aggregate sources were lower than 10%.

The aggregate sources that yielded MDA values smaller than 10% were CG1, CG2, CG3, GA2, GR2, LS5, and LS7, which would be considered adequately performing aggregate sources. However, current DoD specifications do not include the MDA test method. Therefore, no acceptance criterion exits in the current construction guidance that can discriminate the quality of the aggregate sources based on the MDA value.

The MDA test results were also analyzed by grouping the MDA values on box plots based on the test sample grades (e.g., 12.5 versus 9.5 mm grades). Figure 13 shows the box plots created to compare the overall distribution of the MDA values by test sample grade. Both data groups had a sample size of ten. Based on the median MDA values of 12% and 14%, the 12.5 and 9.5 mm box plots, respectively, yielded very similar test results. From these box plots, the 9.5 mm grade exhibited a greater range of MDA values than that of the 12.5 mm grade. The box plot for 9.5 mm sample grade showed the smallest MDA value.

Table 6. Summary of MDA test results.

Aggregate Reference	Aggregate Type	MDA Test Results			
		Sample Grade	Average	Standard Deviation	Coefficients of Variation (COV)
CG1	Crushed Gravel	12.5	2%	0%	7%
		9.5	2%	0%	1%
CG2		12.5	9%	1%	7%
		9.5	10%	0%	2%
CG3		12.5	8%	0%	4%
		9.5	9%	1%	6%
CG4		12.5	14%	1%	7%
		9.5	13%	0%	1%
CG5		9.5	12%	0%	2%
GA1	Gabbro	TBD	—	—	—
GA2		9.5	9%	0%	3%
GR1	Granite	12.5	13%	0%	1%
GR2		12.5	10%	3%	28%
		9.5	10%	1%	6%
GR3		TBD	—	—	—
GR4		TBD	—	—	—
GW1	Graywacke	9.5	16%	1%	9%
LS1	Limestone	12.5	20%	0%	2%
		9.5	19%	0%	2%
LS2		12.5	14%	1%	5%
		9.5	14%	1%	4%
LS3		12.5	15%	0%	2%
		9.5	16%	0%	0%
LS4		12.5	14%	0%	1%
		9.5	15%	0%	2%
LS5		12.5	11%	1%	5%
		9.5	10%	2%	17%
LS6		12.5	14%	0%	3%
		9.5	14%	2%	16%
LS7		12.5	7%	1%	9%
LS8		TBD	—	—	—
MZ1	Monzonite	9.5	12%	0%	0%
MZ2		TBD	—	—	—
SS1	Sandstone	12.5	20%	1%	3%
		9.5	20%	0%	0%
SS2		12.5	19%	0%	1%

Figure 12. Distribution of typical MDA test results.

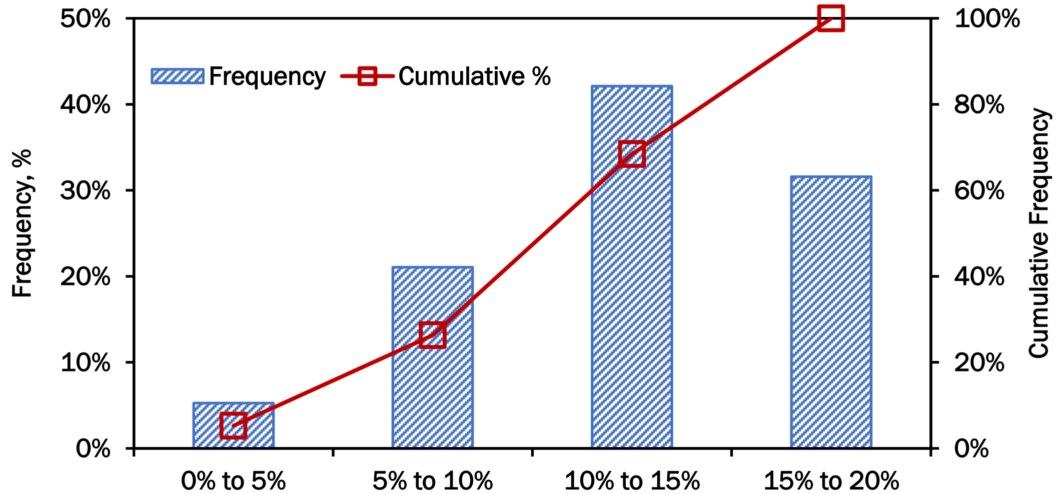
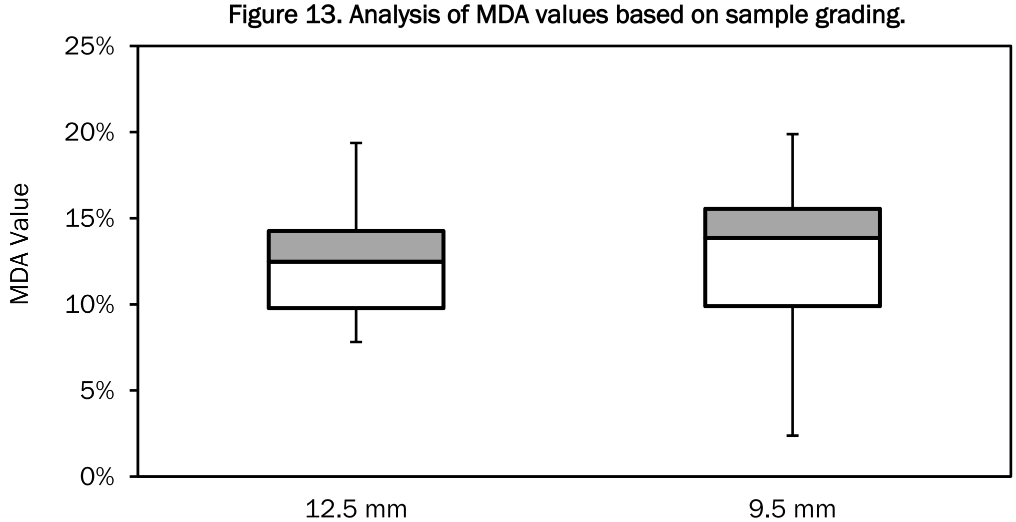
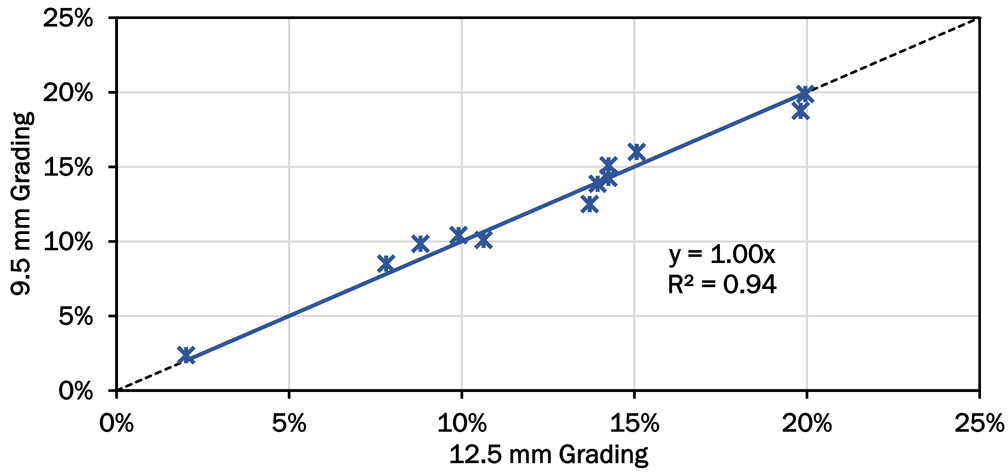


Figure 13. Analysis of MDA values based on sample grading.



To check whether the test sample grade could have an impact on the MDA values, some of the aggregate sources were tested using test sample grades of both 12.5 and 9.5 mm. The equality plot from Figure 14 was created with the data generated from this exercise. The results from the 12.5 mm sample grade are shown in the abscissa of the equality plot, while the ordinate corresponds to the 9.5 mm sample grade. As it was observed from the LAA test results, the test sample grade did not impact the MDA values. This could be confirmed with the resultant R^2 of 0.94 and a slope value of 1.00 for the linear function fitted through the data points.

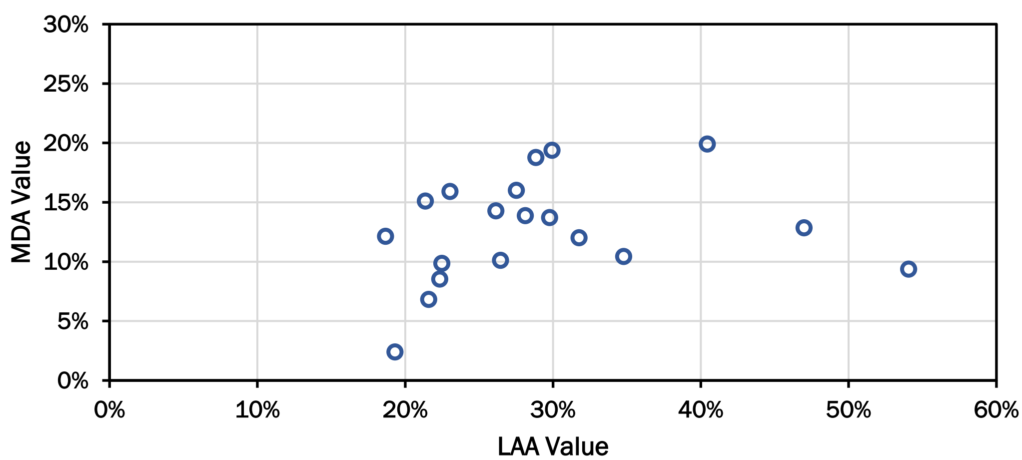
Figure 14. Equality plots for relation of MDA test sample grading designations.



7.2 Relationship between LAA and MDA Parameters

An overall correlation analysis was conducted for the LAA and MDA test results, as seen in Figure 15. As can be seen from this graph, no relationship exists between these two aggregate tests, although they both proport to measure abrasion resistance of aggregate. However, there are a few differences in the testing mechanisms between these two tests. The most obvious is that aggregates are tested in water for the MDA test method, while the aggregates are dry for the LAA test method.

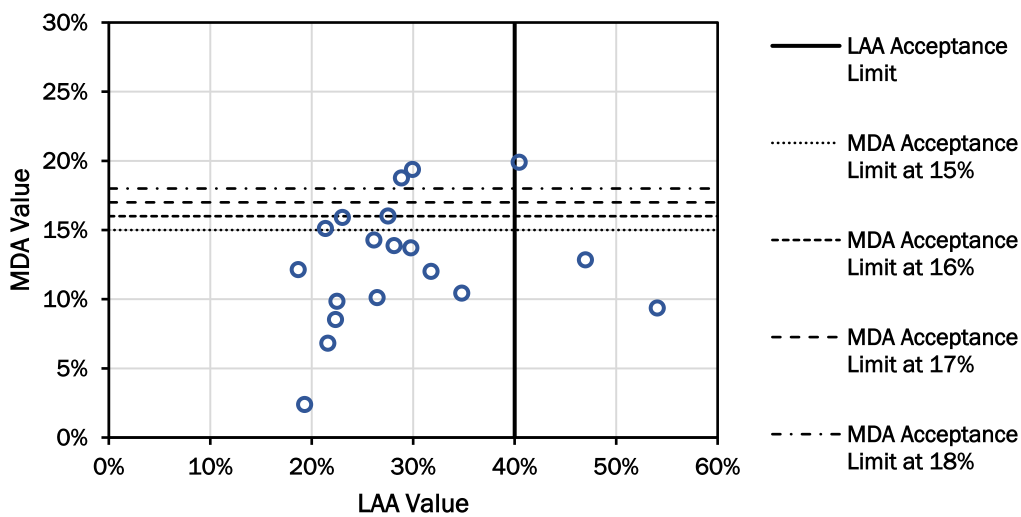
Figure 15. Relationship between LAA and MDA test results.



The MDA test method is not currently specified by the DoD for testing of aggregate sources. Therefore, no acceptance limit can be employed to discriminate the abrasion resistance of aggregates with the MDA test. Several state DOTs—including Colorado, Texas, South Carolina, Montana, Oregon, and Oklahoma—currently specify the MDA test. These DOTs have different acceptance limits to differentiate between acceptably and poorly performing aggregates. For example, the Texas, Virginia, and Colorado DOTs specify a maximum MDA value of 15%. South Carolina and Alaska DOTs specifies a maximum MDA value of 17% and 18%, respectively.

In this study, the MDA values collected were discriminated with four preliminary acceptance limits (15%, 16%, 17%, and 18%). Figure 16 shows the relationship between MDA and LAA test results with the corresponding acceptance limits, and Table 7 summarizes the aggregate sources that did not meet the preliminary acceptance limits for the MDA test. From the LAA test results, three aggregate sources did not meet the maximum acceptance limit of 40%. From these three aggregate sources, only one aggregate source does not meet any of the preliminary acceptance limits for the MDA test. This aggregate source corresponds to a sandstone aggregate.

Figure 16. Analysis of MDA and LAA test results based on acceptance limits.



By analyzing only the MDA test results and preliminary acceptance limits, we observe that, in general, more aggregate sources would be screened out in comparison to using the LAA test. Specifically, six aggregate sources will be screened out if the MDA acceptance limit is set at 15%. With an MDA acceptance limit of 16%, five aggregate sources will be considered poorly performing. Three aggregate sources will be discarded if the MDA acceptance limit is set at 17% and 18%. From these analyses, we observe that the aggregate types that did not meet the MDA acceptance limits were greywacke, limestone, and sandstone, which are historically considered of lower quality than other aggregate types, such as granite and crushed gravel.

Table 7. Acceptance of aggregate sources based on MDA test results.

Aggregate Reference	MDA Acceptance Limit of			
	15%	16%	17%	18%
CG1	—	—	—	—
CG2	—	—	—	—
CG3	—	—	—	—
CG4	—	—	—	—
CG5	—	—	—	—
GA1	—	—	—	—
GA2	—	—	—	—
GR1	—	—	—	—
GR2	—	—	—	—
GR3	—	—	—	—
GR4	—	—	—	—
GW1	X	X	—	—
LS1	X	X	X	X
LS2	—	—	—	—
LS3	X	X	—	—
LS4	X	—	—	—
LS5	—	—	—	—
LS6	—	—	—	—
LS7	—	—	—	—
LS8	—	—	—	—
MZ1	—	—	—	—
MZ2	—	—	—	—
SS1	X	X	X	X
SS2	X	X	X	X
Unacceptable aggregate sources	6	5	3	3
Percentage of unacceptable aggregate sources	32%	26%	16%	16%

8 Summary

Under the UFGS 32 12 15.13 specification (USACE 2013), subsection 2.3.1 “Coarse Aggregate” requires the use of sound, tough, and durable particles, which is achieved by selecting aggregate sources that meet two test methods: the MSS and the LAA test methods. Additional requirements are also specified in terms of fractured faces, particle shape, slag-related material, and clay lumps and friable particles. The use of high-quality pavement materials contributes to minimizing FOD problems, such as aggregate-related pavement degradation. An experimental evaluation of the LAA test and associated acceptance limit was carried out to verify that aggregates with satisfactory quality are used for airfield asphalt paving projects. A representative number of aggregates, including different types and sources, were evaluated with the LAA test per the methods of ASTM C131 (2020b). A review of existing specifications from state DOTs was also conducted to compare their practices with current DoD specifications.

8.1 Conclusions

The results from this initial verification of the LAA test and associated acceptance limit yielded the following conclusions:

- Most DOTs specify an acceptance limit of 40% or greater for the LAA test, while the DoD also specifies an LAA acceptance limit of 40%. Based on this general comparison of current practices, we conclude that an acceptance limit of 40% for the LAA test is generally considered acceptable practice across a representative number of agencies.
- Most of the aggregates tested in this study exhibited LAA values between 20% and 30%. Only four aggregates sources yielded LAA values greater than 40%. These underperforming aggregate sources corresponded to two granites, a gabbro, and a sandstone aggregate. The LAA test yielded repeatable results with coefficients of variation (COVs) lower than 8%, except for three aggregate test results that yielded COVs of 27%, 15%, and 11%.
- A limited number of aggregate sources were tested using two different aggregate test sample grading designations to investigate any impact on the LAA test results. Regardless of the aggregate sample grading designations, the LAA test results were consistent and representative of the aggregates’ abrasion resistance as measured by the LAA test.

- The MDA test was evaluated as a surrogate to the LAA test. Most of the aggregate sources yielded MDA values that were lower than 15%, while 30% of the aggregate sources tested exhibited MDA values between 15% and 20%. Most MDA test results had COVs lower than 17%, except for one aggregate source with a COV of 28%. It must be noted that only two replicate aggregate samples were tested under the MDA test. Like the LAA test, the MDA test generates consistent results regardless of the aggregate sample grading. Although an acceptance limit for the MDA test is not published in DoD specifications, most aggregate sources would satisfactorily pass a maximum MDA limit of 18%.

8.2 Recommendations

The current specifications are applicable for aggregate selection only during the design process of asphalt mixtures, while minimal testing is carried out during the production of asphalt concrete. This raises the following questions, which are interpreted as research needs in the posed topic:

- Current specifications do not provide a robust testing process to ensure consistency in the quality of aggregate during production and construction. It is well known that the properties and quality of aggregate sources can vary considerably during production of asphalt mixtures and construction of asphalt pavements. Can we adequately characterize the properties of mineral aggregates with the sampling and testing frequency currently followed for an airfield asphalt-paving project?
- The LAA test is currently the test method for assessing the degradation potential of aggregates. The aggregates experience degradation throughout the entirety of the airfield asphalt-paving project. While the LAA test is fundamentally applicable to determine the degradation of aggregates due to abrasion, impact, and grinding, this test method has been criticized as time consuming, tedious, and impractical for routine testing. How can current aggregate test methods be used as part of a quality control testing protocol to monitor the properties of aggregates during production and construction at the project level?
- The MSS and LAA tests are used to assess the soundness and toughness of aggregate sources. Are there other test methods superior to these in terms of (a) time and cost associated with testing, (b) reproducibility of test results, and (c) ability to relate to actual field performance that could be considered to characterize the properties of

aggregates not only during the design process of an asphalt mixture but also during pavement construction?

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Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ACV	Aggregate crushing value
AFCEC	US Air Force Civil Engineer Center
AIV	Aggregate impact value
ASTM	American Society for Testing and Material
CAFB	Columbus Air Force Base
COV	Coefficients of variation
DOT	Departments of Transportation
ERDC	US Army Engineer Research and Development Center
FOD	Foreign object debris
GSL	Geotechnical and Structures Laboratory
LAA	Los Angeles abrasion
MDA	Micro-Deval abrasion
MFR	Memorandum for Record
MSS	Magnesium sulfate soundness
NCHRP	National Cooperative Highway Research Program
PG	Performance Grade
TSR	Tensile strength ratio
UFGS	Unified Facilities Guide Specifications
USACE	US Army Corps of Engineers

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14. ABSTRACT
Low-quality mineral aggregates can potentially lead to production, construction, and long-term performance-related problems in asphalt concrete pavements. Therefore, effective qualification criteria for mineral aggregates are paramount. This study was performed to investigate the effectiveness of the Los Angeles abrasion (LAA) test to assess the abrasion resistance of coarse aggregates commonly used in airfield asphalt paving. The LAA test acceptance criteria currently specified by state departments of transportation were examined and compared to the current Department of Defense criterion. Additionally, recent experiences during a forensic evaluation to identify potential sources of excessive presence of foreign object debris on an airfield runway are also briefly discussed in this report. The LAA test and associated acceptance criterion in Unified Facilities Guide Specification (UFGS) 32 12 15.13 were evaluated by testing 24 aggregate sources from various US locations. Also, the Micro-Deval abrasion test was performed as a surrogate abrasion resistance test. Sufficient evidence was not found to suggest adjustments to current LAA test criterion or to recommend the use of an alternative abrasion test. The current UFGS specifications should be improved to provide a more thorough aggregate testing protocol and detailed guidelines regarding aggregate sampling and testing frequency during design and construction of asphalt pavements.

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