

## PREFACE

### SYNTHETIC AGGREGATE RESEARCH REPORTS

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"Performance Studies of Synthetic Aggregate Concrete," by C. E. Buth, H. R. Blank, and R. G. McKeen, *Research Report 81-6*, Texas Transportation Institute, March 1969.

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"A Sandblast Abrasion Test for Synthetic Aggregate Evaluation," by James T. Houston and W. B. Ledbetter, *Research Report 81-8*, Texas Transportation Institute, October, 1969.

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"Evaluation of Shrinkage-Cracking Characteristics of Structural Lightweight Concrete," by R. G. McKeen and W. B. Ledbetter, *Research Report 81-11*, Texas Transportation Institute, October 1969.

"Fired-Clay Aggregates for Use in Flexible Bases," by W. M. Moore, *Research Report 81-12*, Texas Transportation Institute, November 1969.

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"Nonbloated Synthetic Aggregate Concrete," by J. R. Martin, H. Ahmad, W. B. Ledbetter, and S. C. Britton, *Research Report 81-14*, Texas Transportation Institute, October 1970.

"A Recommended Synthetic Coarse Aggregate Classification System (Revised August 1969)," by W. B. Ledbetter, B. M. Gallaway, W. M. Moore, and Eugene Buth, *Special Report*, Texas Transportation Institute, August 1969.

**A SYNTHETIC COARSE AGGREGATE  
CLASSIFICATION SYSTEM — FINAL REPORT**

by

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*Research Report 81-15 (Final)*

*Synthetic Aggregate Research*

*Research Study 2-8-65-81*

Sponsored by

**The Texas Highway Department**

**in cooperation with**

**U. S. Department of Transportation**

**Federal Highway Administration**

May, 1971

**TEXAS TRANSPORTATION INSTITUTE**

**Texas A&M University**

**College Station, Texas**

## **FOREWORD**

The information contained herein was developed on Research Study 2-8-65-81 titled, "Synthetic Aggregate Research (Burned Shales, Clays, and Slates)," in a cooperative research program with the Texas Highway Department and the Federal Highway Administration. The primary objective of this research was to develop a recommended acceptance criterion for synthetic aggregates for use in highway construction.

## ACKNOWLEDGMENTS

The authors wish to acknowledge the guidance and assistance given by the advisory committee for this study. The members are as follows: (a) Texas Highway Department Personnel—Mr. Kenneth D. Hankins, Study Contact Representative and Research Area Representative; Mr. H. A. Sandberg, Jr., Materials and Tests Division Representative; and Mr. Clarence R. Rea, Bridge Division Representative; (b) Federal Highway Administration Personnel—Mr. Edward V. Kristaponis, Division Representative; and Mr. W. J. Lindsey, Regional Representative.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

## ABSTRACT

This, the final report on the study, represents the recommended synthetic coarse aggregate classification system and performance standards for presently envisioned uses within the highway system. The classification system divides the material into two classes—bloating and non-bloating—and each class into several groups of descending physical requirements. A functional grouping of coarse synthetic aggregates is also presented, in which the recommended permissible coarse aggregate group is shown for each highway function, from surface treatments to base materials.

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# 1. Introduction

The Texas Transportation Institute in cooperation with the Texas Highway Department and the Federal Highway Administration has been engaged in a six-year study involving the use of synthetic aggregates\* in highways. Research involving the use of these aggregates in portland cement concrete and in flexible bases was conducted. The over-all objectives of the study were:

Phase 1—Development of a recommended synthetic aggregate classification system and performance standards for synthetic aggregate portland cement concrete.

Phase 2—Development of a recommended criteria for synthetic aggregate base materials.

During the past six years, a total of fourteen technical reports have been prepared, as well as one special report (see inside front cover). In addition, eight arti-

cles have been published in national journals involving phases of this study (see references 1 through 8).

This, the final report on the study, represents the recommended synthetic coarse aggregate classification system and performance standards for presently envisioned uses within the highway system. As such, the recommendations are based on the results of several research studies concerned with synthetic aggregates, including Study 2-14-63-51, "Use of Lightweight Aggregates," and Study 2-9-66-110, "Synthetic Aggregates for Asphaltic Concrete Mixtures." Where recommendations are based on judgment and experience alone (as in the area of surface treatments), from which limited research studies have been performed, these recommendations are so indicated.

This classification system is *not* intended to replace, or supplant, existing requirements for high quality aggregates in highway construction, but rather *is* offered as a supplement to existing aggregate requirements. For example, the requirements for clean, sound, durable aggregates of specified gradations (depending upon their use) are not mentioned herein because they are adequately covered in current Highway Department specifications.

\*For purposes of this study, synthetic aggregates are defined as structural quality aggregates produced by fuzing raw shales or clays in a rotary kiln under intense heat into predominantly amorphous silicates. These aggregates can be broadly divided into two categories: (1) fuzed and bloated aggregates, generally termed structural lightweight aggregates, and (2) fuzed, but not bloated aggregates.

## 2. Summary of the Major Findings of the Study

In this study on synthetic aggregates for portland cement concretes and flexible bases, considerable data were analyzed and conclusions drawn in each of the fourteen technical reports. The more general and major ones are summarized in the following paragraphs. It should be emphasized that these findings relate to the limitations imposed on this study and further generalizations may not be warranted.

1. Sound, durable, high quality portland cement concrete and flexible bases can be constructed utilizing synthetic aggregates, provided the aggregates meet certain requirements.

2. Not all functional uses of synthetic aggregate require the same quality aggregate. Thus, any classifi-

cation system must recognize, and allow, synthetic aggregate of differing qualities for different uses.

3. Laboratory evaluations can, with reasonable assurance, predict field performance of concrete pavements and structures, and flexible bases. Thus new synthetic aggregate sources, if they satisfactorily pass certain laboratory requirements can reasonably be expected to perform satisfactorily in the field.

4. The major laboratory requirements developed and verified during the course of this investigation are contained in Chapter 3 of this report. They constitute the aggregate and functional recommendations by the authors in the form of a classification system.

### 3. Classification System

TABLE 1. CLASSIFICATION SYSTEM FOR SYNTHETIC COARSE AGGREGATES

Class	Group	Dry Loose Unit Weight (pcf)		100-Minute Saturation—% Max.	Aggregate Freeze-Thaw Loss—% Max.	Pressure Slaking Value—% Max.	Los Angeles Abrasion Loss—% <sup>2</sup> Tex 410-A Max.
		Max.	Min. <sup>1</sup>				
I (Bloated)	A	55	40	15	7	6	30
	B	55	35	15	7	6	35
	C	55	35	20	15	6	40
	D	55	35	—	—	10	45
II (Non Bloated)	A	—	55	—	7	6	35
	B	—	55	—	15	6	40
	C	—	55	—	—	10	45

<sup>1</sup>This minimum should not preclude the experimental use of a lighter weight aggregate from any new source or up-graded existing source.

<sup>2</sup>The questionable applicability of this test is recognized. However, until research develops a better test, this test is the only one available.

The recommended classification system for coarse synthetic aggregate is presented in Table 1. The table divides the material into two Classes (I and II); Class I is subdivided into four groups (A, B, C and D) of descending physical requirements; and Class II is subdivided into three groups of descending physical requirements (A, B, and C).

A functional grouping of coarse synthetic aggregates is presented in Table 2. In this table, the recommended permissible coarse aggregate group defined in Table 1 is shown for each highway function, from surface treatments to base materials. Here again it should be emphasized that not all highway functions were fully evaluated. But, for completeness, the classification system contains the results of this study, as well as others, together with the authors' best judgment.

TABLE 2. FUNCTIONAL GROUPING OF SYNTHETIC COARSE AGGREGATES

Function	Permissible Aggregate Group
Surface Treatments <sup>1</sup>	IA
Asphaltic Concrete Surfaces <sup>2</sup>	IA, B, IIA
Asphaltic Concrete Bases	IA, B, C, D IIA, B, C
Exposed Lightweight Portland Cement Concrete Structures <sup>3</sup>	IA, B
Portland Cement Concrete Pavements <sup>3</sup>	IA, B
Unexposed Portland Cement Concrete Bases <sup>3</sup>	IA, B, C IIA, B
Flexible Base Materials	IA, B, C, D IIA, B, C

<sup>1</sup>The aggregate should be kept dry during construction.

<sup>2</sup>The 100-minute saturation requirement can be waived.

<sup>3</sup>A maximum concrete autoclave expansion (ASTM C151 modified) of 1500 micro in. per in. should be required (see *Research Report 81-10*).

### 4. Discussion of Classification System

#### 4.1 Dry Loose Unit Weight

Since the dry loose unit weight is used in this classification system as a quality acceptance criterion and since the system is for synthetic aggregates for all highway uses, it is desirable to standardize the gradation on which the dry loose unit weight determination is made. It is recommended that the dry loose weight determination be made in accordance with Tex-404-A. The sample should consist of the as-received 1/2 in. to No. 4 fraction.\* Examination of the THD aggregate gradation specifications for portland cement concrete, surface treatments and hot mix asphalt pavements reveals that a major portion of the aggregate skeleton will normally be included within this size.

\*This sample is not intended to represent the actual gradation specified for the various uses.

The maximum unit weight values used for Group I (55 pcf) were taken directly from ASTM designation C330. In order to delineate Group II from Group I, the minimum unit weights for Group II were set at 55 pcf.

The minimum weight requirement for the Class IA material of 40 pcf is an attempt to recognize the fact that high crushing stresses are created in aggregates used for surface treatments and, thus, "tougher" aggregates with finer vesicular structures are required. Through field observation during construction of synthetic aggregate surface treatments, it has been noted that some of the lighter weight (and hence more vesicular) coarse aggregates degrade during the "rolling" operation. The requirement for a more dense aggregate, together with a strict Los Angeles abrasion loss



(see Section 4.5) should help alleviate this problem at the present time.

The minimum weight requirement of 35 pcf for the Class IB, IC, and ID is to insure that only structural quality coarse aggregates will be used.

#### 4.2 100-Minute Saturation

The resistance of structural lightweight concrete to freezing and thawing as influenced by the coarse aggregate is primarily a function of the degree of saturation of the coarse aggregate. Saturation should not be confused with absorption! Saturation is the volume of voids filled with water divided by the total volume of voids available; whereas, absorption is the weight of water in the voids divided by the weight of the solids. For example, an aggregate may have an absorption of 15 percent by weight and have 50 percent of its void volume filled with water. Thus its saturation would be 50 percent. Another aggregate may have an absorption of 20 percent and have only 30 percent of its void volume filled with water. Thus its saturation would be only 30 percent, although it had a higher absorption than the first aggregate.

Laboratory tests have shown that when the degree of saturation is kept below about 25 percent, the concrete exhibits good resistance to freezing and thawing deterioration.\* The degree of saturation of the coarse aggregate is primarily influenced by two factors: (1) the length of time that water is available for absorption and (2) the saturation rate of the aggregate. The first of these is a construction practice which may be varied within limits and the second is an aggregate property for which there is presently no practical means of modification except possibly through the aggregate manufacturing processes.

It is possible to mix and place concrete in the laboratory made with *any* of the aggregates studied without the coarse aggregate becoming as much as 25 percent saturated at the time of mixing. However, the saturation rate of some of the aggregates is so rapid that the precautions necessary to keep the saturation below 25 percent make it impractical to use these aggregates in the field. For this reason, a limiting value of saturation rate that will exclude these aggregates from Class IA and IB has been imposed by placing a maximum limit of 15 percent on the 100-minute saturation.

However, it should be emphasized that this maximum limit in no way precludes the possibility of acceptable pretreatment of the aggregate to alter the rate of saturation.

Another point should be emphasized here. If the Class IA aggregates are used for surface treatments such as seal coats, why limit their 100-minute saturation when the limit was established to prevent concrete freeze-thaw damage? The reason for this limit is based on judgment! If an aggregate to be used in a surface treatment can rapidly absorb water (and thus saturate easily), it will easily gather moisture from the air. This moisture can preclude adequate seating, or "sticking," of the rock into the asphalt layer which in time can result in raveling of the surface treatment. Thus, a maximum 100-minute

\*Buth, Eugene, et al., "Performance Studies of Synthetic Aggregate Concrete," *Research Report 81-6*, Texas Transportation Institute, March 1969.

saturation for aggregates to be used in surface treatments is recommended at this time (with the same stipulation of allowing acceptable pretreatment).

#### 4.3 Aggregate Freeze-Thaw Loss

The aggregate freeze-thaw loss was originally developed to test the susceptibility of lightweight aggregates used in asphaltic concrete to the deteriorating factors of weather and climate in service.\* However, it was found that this test correlated well with concrete freeze-thaw results (see *Research Reports 81-3 and 81-6*), which in turn is an indicator of physical durability. Service records indicate those aggregates passing this test exhibit satisfactory performance. Thus, due to the uncertain cumulative effects of time, climate, weather, and traffic on the long term performance of synthetic coarse aggregates, the authors are of the opinion that this test should be specified as a quality control measure.

#### 4.4 Pressure Slaking Value

Laboratory tests have indicated that the most significant thermochemical reaction that occurs in the production of nonbloating synthetic aggregates is the expulsion of the hydroxyl water from the clay minerals.\*\* This expulsion of hydroxyl water, normally termed complete dehydration, appears to be an irreversible reaction (at least under any conditions of environment that are possible for the use of these aggregates in highway construction). Because of the apparent importance of this chemical reaction in the production of synthetic aggregates, a test was designed to indicate the amount of complete dehydration that has occurred during the burning process. It is called the pressure slaking test and it involves cooking the aggregates under water in a common kitchen type pressure cooker and then subjecting them to severe agitation in water. The agitation in water disperses the rehydrated materials and it also produces some abrasion loss similar to the abrasion that occurs in the Texas Highway Department's standard wet ball mill test.

#### 4.5 Los Angeles Abrasion Loss

While the authors are not convinced that this particular test yields meaningful data in all cases, they are convinced that some means of assessing mechanical wearing strength must be included in any classification system. Therefore, until some more meaningful test is devised, the use of the Los Angeles abrasion test (Tex-410-A) is recommended with the values indicated.

Note that the Class IA aggregate requirement is the most stringent. The reason for this is given in Section 4.1.

#### 4.6 Concrete Autoclave Expansion

The chemical performance of synthetic aggregate concrete has been fully explored in this study (see *Research Reports 81-6 and 81-10*) in an attempt to find

\*Galloway, B. M. and Harper, W. J., "Interim Report on the Laboratory Conditions for the Use of Synthetic Aggregates for Hot-Mix Asphalt Pavements," *Research Report 51-3*, Texas Transportation Institute, November 1966.

\*\*Moore, W. M., et al., "Suitability of Synthetic Aggregates Made from Clay-Type Soils for Use in Flexible Base," *Research Report 81-5*, Texas Transportation Institute, February 1968.

some rapid aggregate test which would preclude aggregates potentially reactive with portland cement. While reactive aggregates were discovered, no aggregate test was found which would isolate reactive synthetic aggregates. Thus, the authors are forced to recommend the

more time-consuming concrete autoclave expansion test. This test need not be a job control requirement. Instead it should serve as a source qualification measure for those aggregates proposed for use in portland cement concrete (see Table 2).

## 5. Discussion of Functional Grouping

### 5.1 Surface Treatments

The advantageous use of synthetic aggregates as coverstone for seal coats and surface treatments is based primarily on the practical factors, the relative importance of which may not be easily judged. The factors are a) improved skid resistance and b) reduced damage to head lamps, windshields and car body finish.

To realize both of these advantages the synthetic aggregate should be light in weight. The arbitrary division point of 55 pcf set by ASTM C330 and other specifications is an acceptable value. Research reported by Gallaway and Harper\* has shown rather conclusively that essentially no head lamp or windshield damage is caused by "flying stone" on seal coat construction projects which utilize cover aggregate weighing less than about 55 pcf.

The use of synthetic aggregate which has a unit weight in excess of 55 pcf has been successfully used in Texas to produce non-skid highway surfaces in the form of seal coats as well as thin hot mix overlays; however, as the unit weight of such aggregate approaches that of average natural aggregate, the potential damage caused by "flying stone" increases and thus this presupposed advantage is minimized.

The classification system outlined in Table 1 specifies a minimum unit weight of 40 pcf for Class IA and 35 pcf minimum for Classes IB, C and D. These limitations are suggested with the full knowledge that several hundred miles of satisfactory seal coats have been constructed in Texas utilizing lightweight synthetic aggregates that weigh less than 40 pcf. Such aggregates came from a single source. Presently, another aggregate in the less than 40 pcf category is available in Texas but to the authors' knowledge this material has not been used as coverstone for seal coats.

According to present information, a third producer will enter the market within about one year with still another lightweight synthetic aggregate which supposedly will weigh less than 40 pcf.

The point of bringing out this information is that the classification system and the functional grouping has been developed utilizing service records as a primary basis of judgement. It would therefore seem unfair to write out a new or improved aggregate on the basis of an arbitrary unit weight value. Proof of serviceability would necessarily be required and therefore some provision should be made wherein a producer would be allowed to demonstrate the serviceability of his product irrespective of specifications which have been, in effect, written around existing materials produced by methods which have been more or less standardized. This is to

say that the door must always be left open to new developments to encourage pioneers in this rapidly changing area.

There is no question but that several lightweight aggregate seal coat jobs have exhibited distress shortly after construction. More problems have arisen with the single source aggregate that has a unit weight less than 40 pcf but at the same time several "failures" have been experienced with synthetic aggregate seals utilizing aggregate from other sources that weighed more than 40 pcf. The success of any such seal coat is hinged on aggregate "quality" and several other rather important and well known factors.

One additional point should be made. The use of synthetic aggregate seal coats, not specifically a part of this study, is now under investigation in Study 2-6-71-83, "Synthetic Aggregates for Seal Coats—An Exploratory Study." As results are obtained on this seal coat study the classification system may change.

### 5.2 Exposed Lightweight Portland Cement Concrete Structures

The limitation placed on 100-minute saturation values does not, by itself, insure that a durable concrete will be obtained. Adequate control of the prewetting operations must be exercised to insure that the coarse aggregate is less than 25 percent saturated at the time of mixing. Some aggregates require an extended period of wetting before 25 percent saturation can be reached, but for others 25 percent saturation can be obtained after a very short period of wetting. At the present time there is no existing test method for determining the degree of saturation of a sample of prewetted aggregate.

Freezing and thawing action is not a serious problem in many areas of Texas. Thus it is recommended that Class IC coarse aggregate may be used in areas where, in the engineer's opinion, the environmental exposure is sufficiently mild or when adequate construction control is exercised to insure that the degree of saturation of the coarse aggregate at the time of mixing is less than 25 percent.

### 5.3 Pavements and Unexposed Portland Cement Concrete Bases

Although no benefit due to decreased weight can be realized from the use of lightweight aggregate in this class of concrete, an improvement in skid resistance may be evident and the aggregate is certainly of sufficient quality to produce good concrete. Therefore, its use is recommended.

For those concretes which will not normally be subjected to wear or abrasion, the Los Angeles abrasion loss requirement could be waived. By so doing, some additional aggregate could be made available for use, thereby achieving a savings in material costs.

\*Gallaway, Bob M. and Harper, William J., "Laboratory and Field Evaluation of Lightweight Aggregates as Coverstone for Seal Coats and Surface Treatments," *Highway Research Record No. 150*, Highway Research Board, 1966, pp. 25-81.

## 6. Implementation Statement

Results from the Institute's studies in the area of synthetic aggregate performance have been implemented, to a large extent, already. This is evidenced by the fact that several THD Special Provisions and Special Specifications have been approved utilizing portions of the first published classification system (see preface). Specifications utilizing the prior recommendations include surface treatments, lightweight concrete for structures, asphaltic concrete, concrete pavement, and flexible bases.

The Highway Department should change their specifications to reflect these revised classification system requirements, and follow these changes through the field utilization of the specifications to ascertain their effectiveness in providing high quality synthetic aggregates for highway uses.

The foregoing statement represents the combined opinion of the study contact representative and the authors. It should not be construed as departmental policy.

The published version of the report, as well as the other fourteen reports on this study (see inside front cover), may be obtained by addressing the request to:

R. L. Lewis, Chairman  
Research and Development Committee  
Texas Highway Department, File D-8  
11th and Brazos  
Austin, Texas 78701 (Phone: 512-475-2971)

## 7. Test Methods

### 7.1 Dry Loose Unit Weight

The dry loose unit weight determination shall be made in accordance with Tex-404-A.

The sample shall consist of the as-received  $\frac{1}{2}$  in. to No. 4 fraction.

### 7.2 100-Minute Saturation

The 100-minute saturation value is calculated from data obtained from the determination of absorption and dry bulk specific gravity and the determination of absolute specific gravity by the pressure pycnometer. The test method is fully described in Tex-433-A.

### 7.3 Aggregate Freeze-Thaw Loss

On the basis of TTI research this test has been tentatively standardized as Tex-432-A. Subsequent to its incorporation TTI has run an additional series of test evaluations to see if the test, as written, was fully repeatable as well as reliable. Results of this investigation reveal that the test procedure should be revised to tighten certain aspects in order to improve repeatability and reliability. Specifically, the following changes are recommended in the Test Procedure as written in Tex-432-A, dated January 1, 1971.

1. Under Step 1 of "Procedure," the sample, after oven drying and weighing, should be soaked in distilled water for a minimum of 24 hours before testing.

2. Under Step 3 of "Procedure," the freezing cycle time for ample freezing of water should be specified as 60 min  $\pm$  15 min.

3. Under "Sample," for those coarse aggregates containing more than 15 percent retained on any sieve size not covered in the test, that additional size should be evaluated as follows:

Passing the  $\frac{3}{4}$  in., retained on the  $\frac{5}{8}$  in. sieve—75 particles.

Passing the No. 4 sieve, retained on the No. 10 sieve—400 particles.

### 7.4 Pressure Slaking Value

The pressure slaking value is determined in accordance with Test Method Tex-431-A Tentative. A number of special tests have been done to check the correlation indicated between the two alternate procedures which are given in this test method for determining the pressure slaking value. The results of these tests have further confirmed that the test procedures are correlated and that either of the test procedures can be used with equivalent confidence.

### 7.5 Concrete Autoclave Expansion

In the development of a testing procedure for the reactivity analysis of synthetic aggregates, considerable use was made of the many early studies. The method basically involves the selective curing of concrete prisms for the purpose of detecting disruptive reactivity. The resulting test is described as follows in the form of the recommended step by step procedures to be used.

*Coarse aggregate preparation*—All synthetic aggregates are to be crushed and screened to a grading range of passing the  $\frac{1}{2}$  in. sieve and retained on the No. 30 size. Immediately prior to mixing, the crushed aggregate shall be soaked in water for the length of time required for the saturation of 30 percent of the aggregate's voids.

*Fine aggregate*—A naturally occurring siliceous fine aggregate meeting the requirement of ASTM C33 shall be used.

*Concrete mix design*—The aggregates shall be proportioned such that the sieve analysis of the combined aggregates meet the grading requirements of ASTM C330 for the  $\frac{1}{2}$  in. to 0 grading range. The cement is to be proportioned by loose volume as specified in the lime popout test of ASTM C330. The mix water shall be that required to produce a slump of 3 in.  $\pm$   $\frac{1}{2}$  in. No admixtures are permitted.

*Concrete specimens*—Three concrete prisms, 2 in. x 2 in. x 11¼ in. are to be prepared from each concrete batch in accordance with the general provisions of ASTM C157 and ASTM C192. Stainless steel gage points shall be embedded as provided in ASTM C490.

*Initial curing*—The specimen shall be moist cured for 24 hours ± 1 hour according to the procedure set forth in ASTM C151.

*Autoclaving*—After the initial curing period, length measurements shall be made to the nearest 0.001 in. and then the specimens autoclaved according to the procedures set forth in ASTM C151. Following autoclave testing, the specimen lengths are to be again measured

and the specimens examined for evidence of cracks, popouts and chemical reactions. The apparatus used for determining the change in length of the specimens shall be a device conforming to the specifications given by ASTM C490.

#### REPORT

The report shall include the following data:

1. Aggregate and concrete identification.
2. Initial gage readings, standard bar readings, and final gage readings.
3. Autoclave expansions, in inches per inch, based on a nominal 10-inch gage length.

## 8. References

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