

# ROTARY KILN-FIRED SYNTHETIC AGGREGATES MANUFACTURED FROM TEXAS LIGNITE FLY ASH

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The use of manufactured synthetic aggregates is increasing because of the depletion of natural aggregate supplies and the trend toward widespread use of lightweight construction materials. Waste materials as well as natural clays, shales, and slates are being used to manufacture these synthetic aggregates. This investigation is a study of the production of a synthetic aggregate from fly ash, a waste product of an electric power plant. The effects of several agglomerating and extrusion aids on an extruded kiln-fired fly ash aggregate are examined in this study. The physical properties of these aggregates were obtained and compared with ASTM Specification C 330 and with the recommended synthetic coarse aggregate classification system of the Texas Transportation Institute. It was concluded that five of the six kiln-fired aggregates are suitable for asphaltic concrete surfaces and bases, unexposed portland cement concrete, portland cement concrete pavements, base courses, and coverstone for seal coats and surface treatments.

• THE USE of manufactured lightweight aggregates in the construction of buildings and highways has become widespread in the last few years. The production of these lightweight aggregates has increased because of the engineering advantages of such lightweight materials as well as the depletion of locally available natural aggregates. Although most of these lightweight aggregates are produced from naturally occurring materials (clay, shale, and slate), industrial waste products such as fly ash are also being used.

Even though in 1969 only eight aggregate manufacturers in the United States were producing synthetic aggregate made from fly ash (1), the utilization of fly ash in this manner is becoming increasingly accepted. Fly ash is not only used in lightweight aggregate but is also used as a cement replacement and as a soil stabilizer (2). The ease of accessibility and low cost as well as its favorable properties make fly ash an excellent raw material for the production of synthetic aggregate. The fact that fly ash is an industrial waste material that presents an enormous disposal problem also enhances its appeal.

The synthetic aggregate manufacturing processes currently being used involve agglomeration of the raw materials and firing of these materials at a high temperature (2,000 F). The agglomeration phase can be accomplished by using pelletizing devices such as a revolving disk, a pelletizing drum, or a pugger-extruder. The extrusion process has several advantages over the other methods (3) including (a) the elimination of the need for secondary crushing, (b) simplification of plant operation, (c) superior performance in concrete (improved workability and higher strengths), and (d) efficient mixing of additives. The firing process is accomplished either by a sintering (traveling grate) process or by a rotary kiln operation. The aggregates produced in this study were pelletized by extrusion and fired in a pilot rotary kiln.

## MATERIALS

This investigation considered various combinations of fly ash, five agglomerating agents, and nine additives. The fly ash used was a lignite fly ash produced in the operation of a power plant near Rockdale, Texas. It was collected by a mechanical separator and is therefore relatively coarse. The chemical and physical properties of this Rockdale fly ash (4, 8) are given in Table 1.

Several materials were investigated to aid agglomerating and extrusion. Because the extrusion process requires a cohesive material with low interparticle friction, the pelletization of fly ash by extrusion methods often requires greater quantities of agglomerating and extrusion aids than would be necessary for pelletizing fly ash by other devices. Because of this need for cohesion and low internal friction, clays or shales are generally chosen as agglomerating agents. In this study, five such materials were studied: (a) a commercial kaolinite clay, (b) an Eagle Ford shale from near Midlothian, Texas, (c) a clay from near College Station, Texas, (d) a by-product resulting from processing bauxite referred to as "red mud", and (e) an organic clay from near Fairfield, Texas.

The study plan called for an investigation of the feasibility of using selected agglomeration agents and extrusion aids in combination with the Rockdale lignite fly ash. The additives and bloating agents used included crude oil, asphalt emulsions, soap, pine oil, commercial air-entraining agents, calcium chloride, sodium bicarbonate, vinsol resin, and corn starch. More than 50 combinations of these materials in different proportions were mixed and evaluated. The major basis of evaluation was the ease of extrusion of the fly ash mixture. The more favorable formulations chosen for further investigation included all five agglomerating agents with vinsol resin. All other additives were eliminated because of lack of cohesion or excessive internal friction developed in the extruder. After further investigation, the College Station clay and the Fairfield clay were excluded as feasible constituents because these materials did not produce pellets of sufficient strength to withstand handling operations associated with rotary kiln operations.

## AGGREGATES

### Production

The mixes chosen for further investigation were pelletized by means of a pugger-extruder, which extrudes the mixture through a steel die, producing pellets of various diameters ( $\frac{1}{4}$ ,  $\frac{3}{8}$ ,  $\frac{1}{2}$ , and  $\frac{3}{4}$  in.). The lengths of the pellets are controlled by use of a wire cutter or other appropriate device. These pellets were then divided into three groups, each with a different drying time. One group was not allowed to dry, whereas the other groups were allowed 24 to 48 hours to dry. Each group of pellets was then

TABLE 1  
ROCKDALE FLY ASH ANALYSIS

| Properties <sup>a</sup>  | Percent by Weight  |
|--|--------------------|
| Chemical   |                    |
| Silicone dioxide (SiO <sub>2</sub> )   | 33.9               |
| Aluminum oxide (Al <sub>2</sub> O <sub>3</sub> )                                   | 18.1               |
| Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )                                     | 6.6                |
| SiO <sub>2</sub> + Al <sub>2</sub> O <sub>3</sub> + Fe <sub>2</sub> O <sub>3</sub> | 58.5               |
| Calcium oxide (CaO)  | 21.9               |
| Magnesium oxide (MgO)  | 1.8                |
| Sulfur trioxide (SO <sub>3</sub> )   | 2.2                |
| Available alkali (NA <sub>2</sub> O)   | 0.7                |
| Physical   |                    |
| Ignition loss  | 6.0                |
| Retained on No. 325 sieve  | 37.0               |
| Blaine fineness  | 2,115 <sup>b</sup> |
| Specific gravity   | 2.57 <sup>c</sup>  |

<sup>a</sup>Data taken from Manz (4, 8).

<sup>b</sup>In cm<sup>2</sup>/gm.

<sup>c</sup>Not percentage by weight.



Figure 1. Pilot rotary kiln at Texas A&M University.

TABLE 2  
PHYSICAL PROPERTIES OF THE AGGREGATES

| Sam-<br>ple<br>No. | Materials                                   | Apparent<br>Specific Gravity |                       | Bulk<br>Specific Gravity |                       | Porosity<br>(percent) | 14-Day<br>Absorp-<br>tion<br>(percent) | 100-Min<br>Satura-<br>tion<br>(percent) | Recom-<br>bined<br>Unit<br>Weight <sup>a</sup><br>(lb/cu ft) | Unit<br>Weight<br>as<br>Produced<br>(lb/cu ft) |
|--------------------|---|------------------------------|-----------------------|--------------------------|-----------------------|-----------------------|--|---|--|--|
|                    |   | Aver-<br>age                 | Range<br>of<br>Values | Aver-<br>age             | Range<br>of<br>Values |                       |  |   |  |  |
| RM5                | Red mud, 5%<br>Vinsol resin, 0.25%          | 2.67                         | 2.66-<br>2.67         | 2.19                     | 2.17-<br>2.21         | 18.1                  |  | 7.43                                    |  | 48.2   |
| K5-1               | Kaolinite clay, 5%<br>Vinsol resin, 1%      | 2.72                         | 2.71-<br>2.74         | 2.16                     | 2.15-<br>2.18         | 20.6                  | 6.33                                   | 9.76                                    | 59.8   | 54.8   |
| M5                 | Midlothian clay, 5%<br>Vinsol resin, 0.25%  | 2.66                         | 2.61-<br>2.69         | 2.14                     | 1.99-<br>2.22         | 19.4                  | 5.01                                   | 14.23                                   | 60.3   | 54.0   |
| M10                | Midlothian clay, 10%<br>Vinsol resin, 0.25% | 2.62                         | 2.57-<br>2.65         | 2.17                     | 2.17-<br>2.18         | 17.2                  | 6.80                                   | 20.46                                   | 58.3   | 53.0   |
| K5                 | Kaolinite clay, 5%<br>Vinsol resin, 0.25%   | 2.78                         | 2.70-<br>2.80         | 2.19                     | 2.18-<br>2.20         | 21.2                  | 7.75                                   | 18.51                                   | 57.4   | 53.8   |
| K10                | Kaolinite clay, 10%<br>Vinsol resin, 0.25%  | 2.73                         | 2.68-<br>2.76         | 2.20                     | 2.20-<br>2.20         | 19.4                  | 7.37                                   | 14.38                                   | 60.4   | 58.0   |

<sup>a</sup>ASTM Specification C 330 gradation (% in. to No. 4 sieve size).

fired in an electric muffle furnace at temperatures of 2,000, 2,050, 2,100, 2,150, 2,200, 2,250, and 2,300 F. The pellets were then compared and evaluated according to strength, external surface texture, and internal bleb structure. Relatively high-strength, well-developed bleb structure and a rough but nonporous surface texture were, in general, the qualities sought in the examination and evaluation of the pellets.

The mixes chosen for further study were extruded in the same manner as described in the preceding and fed into the pilot rotary kiln (Fig. 1) after being dried approximately 48 hours. The aggregate feed rate, kiln rotation speed, firing temperature, and slope of the kiln were set to ensure a certain retention time of the aggregate and a proper calcining of the aggregate.

### Properties

The aggregates obtained from the kiln firings were subjected to selected laboratory tests and evaluations to determine their physical properties. These tests included sieve analysis, apparent and bulk specific gravity, porosity, 14-day absorption, 100-min saturation, unit weight, Los Angeles abrasion, and aggregate freeze-thaw (5). The results obtained from these tests are given in Tables 2, 3, and 4.

### Evaluation

The kiln-fired aggregates were evaluated with respect to ASTM Tentative Specification C 330 and the Texas Transportation Institute's synthetic coarse aggregate classification system (6), which is given in Tables 5 and 6. This latter classification system is not a substitute for existing specifications but is intended as a supplement to them. Although the aggregates, as produced, do not meet the ASTM grading requirements for lightweight aggregates for structural concrete, they can be manipulated in either of two ways to conform to these specifications. One method is to alter the size distribution of the "green" pellets that are fed into the kiln. In this study, pellets were made in 1/2-, 3/8-, and 1/4-in. diameter sizes, thus affording the operator three sizes to work with in altering the gradation. The other method is to crush the mate-

TABLE 3  
AGGREGATE ABRASION AND FREEZE-THAW  
TEST RESULTS

| Sample Number <sup>a</sup> | Los Angeles<br>Abrasion<br>(percent loss) | Aggregate<br>Freeze-Thaw,<br>50 Cycles<br>(percent loss) |
|----------------------------|---|--|
| RM5                        | 34.7                                      | 5.77   |
| K5-1                       | 20.3                                      | 0.36   |
| M5                         | 26.8                                      | 0.03   |
| M10                        | 31.4                                      | 0.21   |
| K5                         | 39.7                                      | 0.27   |
| K10                        | 23.2                                      | 0.08   |

<sup>a</sup>Refer to Table 2 for description of materials of each sample.

TABLE 4  
AGGREGATE GRADATIONS

| Sieve Size | Cumulative Percent Retained by Weight <sup>a</sup> |        |        |        |       |        |
|------------|--|--------|--------|--------|-------|--------|
|            | RM5  | K5-1   | M5     | M10    | K5    | K10    |
| 1 in.      | 16.8   |        |        |        |       |        |
| 3/4 in.    | 72.8   | 0.63   | 4.65   | 0.98   | 0.0   | 1.45   |
| 5/8 in.    |  | 5.03   | 15.05  | 4.11   | 0.8   | 7.01   |
| 1/2 in.    | 88.0   | 31.03  | 54.15  | 44.77  | 33.1  | 35.75  |
| 3/8 in.    | 91.6   | 50.87  | 80.17  | 80.51  | 46.4  | 47.52  |
| No. 4      |  | 99.71  | 98.64  | 99.38  | 97.7  | 97.92  |
| No. 10     | 97.2   | 99.84  | 99.19  | 99.69  | 98.1  | 99.53  |
| No. 16     |  | 99.85  | 99.43  | 99.78  | 98.4  | 99.70  |
| No. 40     |  | 99.89  | 99.61  | 99.85  | 98.9  | 99.74  |
| No. 80     |  | 99.93  | 99.81  | 99.90  | 99.2  | 99.79  |
| No. 100    |  | 99.94  | 99.83  | 99.91  | 99.3  | 99.80  |
| No. 200    |  | 99.97  | 99.95  | 99.96  | 99.7  | 99.88  |
| Pan        | 100.0  | 100.00 | 100.00 | 100.00 | 100.0 | 100.00 |

<sup>a</sup>Refer to Table 2 for description of materials of each sample.

TABLE 5  
TEXAS TRANSPORTATION INSTITUTE CLASSIFICATION SYSTEM FOR COARSE SYNTHETIC AGGREGATE

| Class            | Group | Dry Loose Unit Weight (lb/cu ft) |      | 100-Min Saturation (percent) | Aggregate Freeze-Thaw (percent loss) | Pressure Slaking Value (percent) | Los Angeles Abrasion (percent loss) Tex 410 A |
|------------------|-------|----------------------------------|------|------------------------------|--------------------------------------|----------------------------------|---|
|                  |       | Max.                             | Min. | Max.                         | Max.                                 | Max.                             | Max.  |
| I (bloating)     | A     | 55                               | 35   | 15                           | 7                                    | 6                                | 35  |
|                  | B     | 55                               | 35   | 20                           | 15                                   | 6                                | 40  |
|                  | C     | 55                               | 35   |                              |                                      | 10                               | 45  |
| II (nonbloating) | A     |                                  | 55   |                              | 7                                    | 6                                | 35  |
|                  | B     |                                  | 55   |                              | 15                                   | 6                                | 40  |
|                  | C     |                                  | 55   |                              |                                      | 10                               | 45  |

rial after kiln-firing to produce the required grading. There are advantages as well as disadvantages to either approach.

Shown in Figure 2 are the raw materials that were used to produce one of the acceptable fly ash aggregates together with samples of portland cement and asphalt concrete specimens made with these aggregates.

TABLE 6  
FUNCTIONAL GROUPING OF SYNTHETIC COARSE AGGREGATES

| Function  | Permissible Aggregate Group | Additional Aggregate Requirements: Potential Reactivity (ASTM C 289) |
|---|-----------------------------|--|
| Surface treatments <sup>a</sup>                         | IA                          |  |
| Asphaltic concrete surfaces <sup>a</sup>                | IA, IIA                     |  |
| Asphaltic concrete bases <sup>a</sup>                   | IA, B, C<br>IIA, B, C       |  |
| Exposed lightweight portland cement concrete structures | IA                          | Innocuous  |
| Pavements and unexposed portland cement concrete        | IA, B<br>IIA, B             | Innocuous  |
| Base materials  | IA, B, C<br>IIA, B, C       |  |

<sup>a</sup>The 100-min saturation requirement is waived for these uses.

To be classified by ASTM as a coarse lightweight aggregate, the dry loose unit weight of the aggregate must not exceed 55 lb/cu ft. In this study, none of the aggregates met this specification and therefore are classified as nonbloating or Class II synthetic aggregates by the TTI classification system. None of these aggregates, however, fall into the Portland Cement Association's range (7) of natural, dense aggregates—75 to 100 lb/cu ft. This places the aggregates in this investigation in a range between normal and lightweight aggregates.

All six aggregates are well within the aggregate freeze-thaw specification for group A classification.

Because these aggregates are in Class II, there is no limit on the 100-min satu-

ration. However, one must realize that, because these aggregates have such a high saturation in the first 100 min, they may pose water-absorption problems when used to batch concrete.

The Los Angeles abrasion requirements for a group A aggregate are met by aggregates RM5, K5-1, M5, M10, and K10. Aggregate K5 falls in the B group.

From the preceding analysis, it can be seen that all the aggregates except K5 fall into the category of a Class IIA synthetic aggregate. Aggregate K5 is classified as a Class IIB aggregate. By referring to Table 6, one can see that aggregates RM5, K5-1, M5, M10, and K10 can be used in asphaltic concrete surfaces and bases, in unexposed portland cement concrete and PCC pavements, or as base material. This classification system does not indicate that these materials can be used as coverstone for seal coats and surface treatments; however, the authors believe that these aggregates could be acceptable. Aggregate K5 is an exception and should not be used in either asphalt concrete surfaces or seal coats because of its excessive abrasion loss. This low abrasion resistance was probably caused by overheating during firing.

Visual inspection indicates that the fly ash aggregates would produce a high coefficient of friction when used as a coverstone for a seal coat or surface treatment or as an aggregate in hot-mix surfaces for highways and airfields.

## CONCLUSIONS

The question of whether or not to use a lightweight synthetic aggregate in place of a natural dense aggregate is usually resolved by service demands and economic considerations. If a synthetic aggregate can effect a net savings or can be justified by providing improved physical properties, it will be used even though its unit cost may exceed that of natural aggregate. When all other variables are constant, the lighter the aggregate the greater the yield and, possibly, the lower the unit cost. There are situations, however, where weight is not an important consideration, as in highway pavements. In such cases, the lightweight or bloated synthetic aggregate may offer very little advantage over the nonbloated synthetic aggregate. In areas where natural aggregates are in short supply or have been depleted, synthetic aggregates (nonbloated as well as bloated) make attractive substitutes.

In areas where natural aggregates are scarce, therefore, kiln-fired fly ash aggregates make excellent aggregates for highway construction applications. As shown in this report, aggregates RM5, K5-1, M5, M10, and K10 are quite acceptable for use in asphaltic concrete surfaces, asphaltic concrete bases, portland cement concrete pavements, base materials, and seal coats and surface treatments. Aggregate K5 is not acceptable as an asphaltic concrete surface aggregate or a coverstone for a seal coat because of its high abrasion loss, but it is quite satisfactory in the other uses given.

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Figure 2. Fly ash and clay mixtures, fired pellets, and finished products using fly ash aggregate.

The opinions, findings, and conclusions expressed in this paper are those of the authors and not necessarily those of the sponsors or Texas A&M University.

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