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LIGHTWEIGHT AGGREGATES: A FEASIBLE OPTION FOR ALASKA?

By

Steve Saboundjian and Rachel Armstrong

Research & Technology Transfer

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This study documents the properties of lightweight aggregates (LWA) and investigates the viability of using them in Alaskan transportation construction projects. The report presents a literature review of LWA (sometimes known as LECA - Lightweight Expanded Clay Aggregates) that are created from expanded shale, clay, and slate. This review revealed that LWA have become an accepted construction material and continue to be an area of active research. These materials have shown their value through their low thermal conductivity, low unit weight, and high internal angle of friction. Besides their common use in lightweight concrete and masonry blocks, their use in roadways as lightweight embankment fill and as insulation material is subject to research and development in the U.S. and especially in the Scandinavian countries. The major obstacle for their use in Alaska is the high importation cost from manufacturing plants in the continental U.S.. However, availability of shale deposits along Alaskan highways and railroads may make the manufacturing of LWA in Alaska economically attractive. While LWA appears to be a promising material for Alaskan conditions, it is essential to determine if the benefits of its use outweigh the increase in cost. This cannot be conclusively answered without constructing experimental road segments, where LWA layers (of variable thickness and depth from the pavement surface) are incorporated in experimental roadways, then monitored over time to capture their behavior and effects in the Alaskan harsh conditions.

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This study documents the properties of lightweight aggregates (LWA) and investigates the viability of using them in Alaskan transportation construction projects.

The report presents a literature review of LWA (sometimes known as LECA - Lightweight Expanded Clay Aggregates) that are created from expanded shale, clay, and slate.

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The major obstacle for their use in Alaska is the high importation cost from manufacturing plants in the continental U.S.. However, availability of shale deposits along Alaskan highways and railroads may make the manufacturing of LWA in Alaska economically attractive.

While LWA appears to be a promising material for Alaskan conditions, it is essential to determine if the benefits of its use outweigh the increase in cost. This cannot be conclusively answered without constructing experimental road segments, where LWA layers (of variable thickness and depth from the pavement surface) are incorporated in experimental roadways, then monitored over time to capture their behavior and effects in the Alaskan harsh conditions.

1- Introduction

Lightweight aggregates (LWAs), produced from expanded shale, clay, or slate, are commonly used around the world for a variety of applications. There are at least 13 U.S. manufacturers, as well as manufacturing companies in Japan, Canada, Norway, Italy, Belgium, Germany, and Venezuela. There are several types of LWAs; however, this study focuses on expanded shale, clay, and slate, which will be referred to as lightweight aggregate (LWA) in this study. Other sources include blast furnace slag, fly ash, and volcanic deposits. The advantages seen in LWAs over conventional aggregates include its high internal angle of friction, increased thermal insulating capacity, freeze-thaw resistance, and low unit weight.

Expanded shale, clay, and slate are produced through pyroprocessing. The two primary methods are the rotary kiln and the traveling grate:

- The rotary kiln consists of a long, slowly rotating, nearly horizontal cylinder lined with refractory materials similar to cement kilns (Holm, 1995). The aggregates created by the rotary kiln method can be coated or sintered aggregates. Heating closely sized shale particles in the kiln (Heiner and Loskamp, 1966) produces coated aggregates, which contain a glassy outer coating. The coating decreases and slows the absorption of the aggregates (Heiner and Loskamp, 1966; Zhang and Gj∅rv, 1991). Sintered aggregates are from "processing large diameter shale particles with subsequent crushing and gradation to aggregate [size] specifications" (Heiner and Loskamp, 1966). The rotary kiln is the preferred method because it can produce the higher quality coated aggregate (Heiner and Loskamp, 1966).
- In the traveling grate process "a bed of raw materials including fuel is carried by a travelling grate under ignition hoods" (Holm, 1995). The traveling grate method produces a sintered aggregates.

In both processes described above, the raw materials are heated to over 2000^{o}F (1090^{o}C). During the firing process, gas formation occurs from the reaction of heat on certain raw material constituents and then gas expansion is trapped in the viscous, pyroplastic mass. "Strong, durable lightweight aggregates are produced when small-size, well-distributed, noninterconnected pores are enveloped in a continuous, crack free, vitreous phase" (Holm, 1995). The pore spaces are the key to the low unit weight of lightweight aggregates. Houston et al. (1969) studied the effect of temperature and retention time in a rotary kiln on the quality of aggregate produced. They concluded that the most effective combination of temperature and retention time depends upon the particular raw material. A typical combination is firing the raw materials for one hour at 2000^{o}F (1090^{o}C).

2- Material Properties of Lightweight Aggregates

Many researchers have investigated physical, thermal and mechanical properties of LWAs. This section presents a summary of their findings.

2-1 Shape

LWA particle shape and surface texture varies widely depending on the source of raw materials and method of production. LWA particles vary in shape: from cubical, rounded, angular, to irregular (Holm, 1995). Two primary attributes that need to be heeded are the high interstitial void content, which results from a narrow range of particle sizes and the high volume of pores within the cellular particle (Holm and Valsangkar, 1993).

2-2 Bulk Density

Particles commonly have an oven dry specific gravity that ranges from 1.25 to 1.40 (Holm and Valsangkar, 1993). The oven dry specific gravity is based on a 24-hour water immersion of the particles, as opposed to a saturated condition for conventional aggregates. Bulk dry densities are commonly in the range of 45 pcf (721 kg/m^3). The porosity of LWA particles is quite high. For an average sample, the dry bulk density is composed of 48% interparticle voids, 24% pores, and 28% ceramic matrix (Holm and Valsangkar, 1993). Impact moist densities can be developed in-place, through compaction, of less than 65 pcf (1042 kg/m^3). Typically, the unit weight of LWAs is equal to half of the unit weight of conventional soils (Mehdiratta and Noggle, 1986).

2-3 Absorption

A typical value for 24-hour absorption is 8.5% (Holm and Valsangkar, 1993), however, LWA will absorb anywhere from 5 to 24% of its dry weight in a 24-hour period (Holm, 1995). Absorption for a LWA tends to be in the interior of the aggregate, while normal weight aggregate primarily experiences surface absorption (Holm, 1995).

For LWAs, absorption of water continues to increase with submersions far longer than 24-hours. In one study, a sample of LWA was kept submerged for 1-year. The absorption increased from the 24-hour absorption of 8.5% to approximately 20% over the course of the year (Holm and Valsangkar, 1993). Holm and Valsangkar suggest that the absorption percentage by weight will approach 34% at infinity. “Complete filling of all pores in a structural grade LWA is unlikely because the noninterconnected pores are enveloped by a very dense ceramic matrix. However, these calculations do reveal a conservative upper limit for submerged design considerations” (Holm and Valsangkar, 1993).

While absorption continues indefinitely, the rate of absorption decreases with time. For instance, Zhang and Gjørv (1991) observed that 70% of the 24-hour water absorption took place within the first 30 seconds of absorption. According to Mehdiratta and Noggle (1986), even after LWA samples have been submerged for one year, they do not show apparent signs of material softening.

2-4 Durability

Long-term durability of LWAs was demonstrated in 1991 by testing reclaimed samples of lightweight fill that had been supplied to a Hudson River site in 1968. Magnesium soundness tests conducted on the sample showed soundness loss values comparable to those reported in quality-control testing procedures 23-years earlier. This result indicated little long-term deterioration from continuous submersion and freeze-thaw cycling at the waterline (Holm and Valsangkar, 1993).

2-5 In-Place Compacted Moist Density

LWA test results from compacted density tests (i.e. Proctor tests) should be interpreted different from the results of natural soils, for two reasons. First, LWAs have a greater absorption than natural soils, which means a portion of the water added during the test will be absorbed. Second, "structural grade" LWAs contain limited fines, which limits the decrease in density that can be obtained from the packing of the fines between the larger particles (Holm and Valsangkar, 1993). The compaction achieved by reorganization of the particles is typically between 10 and 15 percent; further compaction can only be achieved through particle crushing (Watn et al., 2000). "The objective in compacting structural grade lightweight aggregate fill is not to aim for maximum in-place density, but to strive for an optimum density that provides high stability without unduly increasing compacted density. Two to four passes of rubber tire equipment commonly achieve optimum field density. Excessive particle degradation developed by steel-tracked rolling equipment should be avoided" (Holm and Valsangkar, 1993).

Watn et al. (2000) recommend using vibratory or gyratory compaction and keeping stress levels remain below 100 to 150 kPa (14.5 - 21.8 psi) to avoid particle crushing. Mehdiratta and Noggle (1986) agree that LWA should not be compacted for maximum in-place density, since LWA does not have the classical moisture-density curve normally associated with cohesive soil. In fact, when a standard proctor test (ASTM D 698) was performed on three gradations of LWA in an air dry, saturated surface dry, and soaked condition, the maximum dry densities were obtained by compacting the samples in an air-dry state.

Field density can be approximated in the lab using a one-point ASTM D698 (AASHTO T99) Proctor test on a representative sample containing the field moisture content (Holm and Valsangkar, 1993). Project specifications for in-place, compacted, moist density not to exceed 60 pcf (961 kg/m^3) has been successfully achieved many times.

2-6 Shear Strength

Triaxial compression testing has shown that LWAs have characteristically high angles of internal friction. Typical angles for loose material range from 36-40 degrees and for compacted material from 44 to 48 degrees (Gustavsson et al., 2002; Holm and Valsangkar, 1993; and Mehdiratta and Noggle, 1986). Typically LWA has an internal friction angle comparable to dense sand (30-38^o) or gravel (35-40^o) (Mehdiratta and Noggle, 1986). "With a commonly specified in-place moist compacted unit weight less than 60 pcf [961 kg/m^3], it may be seen from a simplistic analysis that lateral pressures, overturning moments, and gravitational forces approach one-half of those generally associated with ordinary soils" (Holm and Valsangkar, 1993).

2-7 Resilient Stiffness

Gustavsson et al. (2002) found the resilient stiffness of expanded clay (a type of LWA) to be in the 100 to 200 MPa range (14.5 - 29.0 ksi), while Watn et al. (2000) found the stiffness to be between 100 and 450 MPa (14.5 - 65.2 ksi). The resilient stiffness is dependent upon both the stress level and grain size distribution (Watn et al., 2000; Gustavsson et al., 2002). Watn et al. (2000) found that Light Expanded Clay Aggregate (Leca) had twice the resilient stiffness in a 0 to 32 mm (0 - 1.3 in) gradation as opposed to a 10 to 20 mm (0.39 - 0.79 in) gradation.

2-8 Compressibility

Compressibility strength of LWA has been demonstrated through large-scale compressibility tests and cyclic plate-bearing tests. LWA fill stress-strain curves from confined compression testing were shown to be similar to curves developed for limestone in the same testing procedures. Cyclic plate-bearing tests showed that lightweight and normal weight aggregate samples have similar vertical subgrade reaction responses (Holm and Valsangkar, 1993). These tests also demonstrate the benefit of geogrid reinforcement in LWA. The bearing stress to cause 12-mm (0.47 in) plate settlement increased from 456 to 1000 kPa (66 - 145 psi) when compacted lightweight aggregate was reinforced with geogrid (Valsangkar and Holm, 1993).

2-9 Thermal Resistance

According to Holm and Valsangkar (1993), it is well demonstrated that LWA has a considerably lower thermal resistance than normal weight aggregate. Mehdiratta and Noggle (1986) documented applying the "Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter" (ASTM C 518-76) testing procedure to two LWA specimens, 20 inches (51 cm) square and 8 inches (20 cm) thick. The samples were composed of ½ inch diameter aggregate. The apparent thermal conductivity of each sample was 0.086 BTU/hr ft ^{o}F (0.149 J/sec m ^{o}C). Watn et al. (2000) found that thermal conductivity increases with water content.

2-10 Permeability

While permeability has not been successfully characterized in the laboratory, projects using LWA in storm water drainage systems and in exfiltration applications have shown its usefulness for these purposes (Holm and Valsangkar, 1993).

2-11 Geotextile Interaction

Tests have shown that the interface friction characteristics between aggregate and geotextiles are, in general, better for lightweight than normal weight aggregates (Holm and Valsangkar, 1993).

2-12 Abrasion Resistance

It has been found that the Los Angeles abrasion test is ineffective “for the evaluation of lightweight aggregates” (Houston and Ledbetter, 1969). The test fails to “show significant differences between various lightweight, easily crushed aggregates, and hard, dense, natural aggregates. In response, they developed their own abrasion test, which they call the Texas sandblast abrasion test for aggregates. The test uses air-driven sand as the abrading mechanism and results in an improved differentiation between aggregates. This test method could be especially helpful in manufacturing of LWAs, because it was able to differentiate “between lightweight synthetic aggregates of various unit weights and degrees of transformations”. The test is described fully in “A Sandblast Abrasion Test for Synthetic Aggregate Evaluation” and recommended for further study, by the authors.

2-13 Classification System

A study by Ledbetter et al. (1971) identified a classification system for synthetic coarse aggregates. The classification system is based on maximum and minimum dry loose unit weight, maximum 100-minute saturation, maximum aggregate freeze-thaw loss, maximum pressure slaking value, and maximum Los Angeles abrasion loss. The classification consists of 7 types of synthetic aggregate classified as class I, groups A-D and class II, groups A-C. Class I is for bloated and class II is for non bloated aggregates. Specific class and group combinations are recommended for specific highway functions. All of the class group combinations are recommended for use in asphaltic concrete bases and flexible base materials.

3- Highway Uses for Lightweight Aggregates

During the literature search, nine papers were recovered that deal with the subject of LWA use in roads. Very little information was found on this topic within the United States. Several states use LWA in asphalt surface treatments. Texas was the only state that appeared to have conducted considerable research into LWA for highway uses other than chip seal. Texas, Norway, Finland, and Sweden were the primary information sources for studies on the feasibility of LWAs as a base course or embankment material.

The papers retrieved from Norway, Finland, and Sweden contained valuable information. In the literature search there appeared to be more information available in these Nordic countries concerning LWA use in road construction, however, many papers have not been translated to English.

According to one Finnish/Swedish research group, expanded clay (Exclay, a type of lightweight aggregate) has two main road-related uses, “either for frost insulation purpose in frost susceptible soils or for lightening of road embankments on soft soils to prevent settlement” (Gustavsson et al., 2002).

A pamphlet by the *Expanded Shale Clay and Slate Institute (ESCSI)* (1994) outlines the advantages of using LWA in asphalt surface treatments (i.e. chip seal or seal coat). The advantages listed are high skid resistance, extension of roadway life, increased freeze/thaw resistance, increased resistance to stripping, and considerable reduction of windshield, headlight, and paint damage from flying stones. One disadvantage mentioned is that LWAs can roll out of the asphalt under constant breaking or turning conditions. A consultant from Texas states that it is their practice to stop slightly short of busy intersections with the LWA surface treatment and switch to another method.

A second roadway use of LWA is for insulation. Primarily the Nordic countries have investigated this use. At this point, LWA use as roadway insulation is still in the experimental phase and appears not to be widely used for this purpose.

In Finland, a test was conducted where expanded clay was used for frost insulation (Gustavsson et al., 2002). Leca (Light Expanded Clay Aggregate) was placed in a test deck in layers from 0.7 to 1.45 m (2.30 to 4.76 ft.). The layers were placed below the road surface at depths of 35, 50, and 70 cm (1.15, 1.64, and 2.30 ft.). The subgrade was soft clay with a thickness from 5 to 10 m (16.4 - 32.8 ft.). Test results showed that the 50 and 70-cm (1.64 and 2.30 ft.) sections had higher surface temperatures than the reference section, while the 35-cm (1.15 ft.) had lower. The higher surface temperatures probably correlate to less frost and icing, although this study was not able to substantiate this. The study recommends keeping the vertical stress below 100 kPa (14.5 psi) when using LWAs in the road, which can be done by keeping the covering depth equal to or greater than 30 cm (1 ft.).

Furuberg et al. (2000) of Norway agree that Leca can be used advantageously as a “combined insulation layer and road building material”. Their experimental results show that even the poorest (i.e. with a large percentage water content) Leca insulation provides “a large reduction in frost penetration compared to an equally thick road without Leca”. Their analysis also showed that while the thermal conductivity of Leca increases with water content, the “frost penetration is hardly influenced by the water content as long as the frost does not penetrate the Leca layer itself”. However, when the frost does penetrate the Leca layer, the frost penetration depth is strongly dependent on the Leca water content. In Norway, the design winter for frost protection of roads is a 10-year return period. The authors conducted an analysis to determine what happens when the winter is colder than the design winter and the frost penetrates the road structure. They found that the “Leca will experience less frost heave during winter and have improved bearing capacity during thaw than a road without Leca” under these circumstances. The frost heave is less because the depth of frost penetration is shallower and the road experiences a shorter period with frost in the subsoil. The bearing capacity is improved during thawing because the “frozen subsoil thaws from beneath and water drain[s] from the thawing front” in a road built with a layer of Leca. “For a road without Leca there will be a ‘plate’ of frozen ground in the subsoil at the end of the thaw season. Above this layer the subsoil and the road structure will have excess water from thawed ice lenses”.

A field investigation, in Leirsund, Norway, was also conducted in conjunction with these investigations. A short section of railway was built and exposed to freezing indexes exceeding 30,000 h ^{o}C (1250 ^{o}C days). One section was built without Leca resulting in a thickness of 2.32 m (7.61 ft.), while in a second section the lower 1.1 m (3.61 ft.) of the crushed rock layer were replaced by 40 cm (1.31 ft.) of Leca. The thickness of the Leca section was 1.62 m (5.31 ft.). The section with Leca did not experience frost heave or frost in the subsoil, while both occurred in the section built with crushed rock. The thermal conductivity was back calculated for the Leca and crushed rock sections as 0.16 - 0.21 W/mK (0.09 - 0.12 BTU/h ft ^{o}F) and 0.6 - 1.1 W/mK (0.4 - 0.6 BTU/h ft ^{o}F), respectively.

Watn et al. (2000) instituted a full-scale laboratory test at Sandmoen in Trondheim, Norway to verify that Leca behaves satisfactorily under real traffic loads. The test section is built to determine what coverage depth Leca needs to avoid deformation. The first layer of the test section is 4 cm (1.6 in) of asphalt. The second layer is 6 cm (2.4 in) of asphalt, which extends only the first 6 m of the 10 m test deck (20 of 33 ft). The third layer progresses from 30 cm (12 in) to 16 cm (6.3 in) of crushed rock. The fourth layer is a 40 cm (16 in) thick layer of 10 - 20 mm (0.39 - 0.79 in) graded Leca. The final layer is sand starting at a thickness of 35 cm (14 in) and progressing to 55 cm (22 in). The test section is 1.15 m (45 in) thick and the Leca progresses from a covering depth of 40 to 20 cm (16 - 7.9 in). Permanent deformations are expected in the Leca at the weak end of the structure. This test deck was installed in June 1999 and conclusions from the analyses of measurements taken from ordinary traffic and controlled loadings will be published later. Results from t0his study will be used as a basis for recommending the use of Leca material for frost insulation in roads in Finland, Sweden, and Norway.

In a report by Sintef Civil and Environmental Engineering, Norway, the following considerations are mentioned for using LWA in the road structure (Watn, 2001):

1- The use of geotextiles in conjunction with LWA is recommended on soft cohesive soils,
2- The maximum thickness of fill layers should be 0.6 m (2 ft.),
3- The recommended maximum contact pressure when leveling and compacting with a caterpillar is 50 kN/m^2 (7.3 psi),
4- A minimum of 6 passes after leveling is recommended,
5- Construction methods should be used that limit crushing and separation,

6- Blowing into place is the recommended placement method for Leca graded 10 - 20 mm (0.39 - 0.79 in). Leca can be blown up to 40 m (130 ft) horizontally and 20 m (65 ft) vertically for some gradings, and
7- Temperatures above $0^{o}C$ ($32^{o}F$) are preferred for placement of Leca.

The Sintef report concludes that "performed research work and experiences from real projects have verified that LWA has physical, mechanical and thermal properties which makes it suitable for use as frost insulation and light weight fill in roads and other traffic areas" (Want, 2001). Challenges to be met in the future include "proper design founded on well proven material properties" and "quality of performed construction in accordance with specifications".

Moore (1970) at the Texas Transportation Institute of Texas A&M University investigated the use of LWAs in flexible bases. The study developed the pressure-slaking test and the modified pressure-slaking test for testing the aggregates' suitability. The test consists of underwater pressure-cooking followed by severe agitation. The study concludes that a synthetic aggregate is acceptable for use in Texas flexible bases when the loss in gradation from the pressure-slaking test is less than 10 percent or less than 4 percent in the modified pressure-slaking test. In addition, the study concluded that synthetic aggregates suitable for flexible bases in Texas could be produced from clay in rotary kilns.

4- Cost Analysis

The adoption of any new method of construction requires a cost justification. The purchase price of LWAs is at least twice that of common fill on a cubic yard basis. Two questions that are important to consider are how much the price difference will be and whether the benefits of using LWA outweigh the increase in price. In order to help answer the first question, this section explores a cost and benefit analysis of an embankment with lightweight fill, give a simple formula for LWA cost per ton to cost per cubic yard, and give a representative price quote for LWA delivery to Fairbanks, Alaska.

In 1991, an analysis was conducted on the benefits of building a road embankment with LWA fill, as opposed to common fill. The embankment was part of a project currently under design by the Texas State Department of Highways and Public Transportation (Brettmann, 1991). The embankment was planned to be 675 ft (206 m) long, 147 ft (44.8 m) wide, and increase in height from 11 to 30 ft (3.4 - 9.1 m). The embankment was to be constructed over compressible soil and a large number of piles were required to reduce settlement if common fill was used. The analyses of the lightweight fill solution included factor of safety, settlement, number of piles necessary, lateral earth pressure, and a cost comparison. This case study will provide a basis for cost comparison analysis.

The minimum computed factor of safety was 0.92 for common fill without piles, 1.21 for lightweight fill without piles, 1.25 for common fill with piles, and 1.86 for lightweight fill with piles. The common fill embankment was planned with a reinforced earth retaining wall supported on piles, while the LWA embankment has nearly the same factor of safety with a reinforced earth retaining wall without a pile foundation. The factor of safety analysis shows that the "increased strength and lower weight of the lightweight aggregate almost balances the effect of a pile foundation beneath the retaining wall for this case" (Brettmann, 1991).

The settlement in this case was reduced from 37 to 23 inches (94 - 58 cm) when constructing the embankment from LWA without piles instead of common fill with piles. If less settlement still was needed in the embankment, then piles could be used with the LWA fill. However if piles are still needed, the number of piles are reduced from 1,820 piles with common fill to 1,365 piles with the lightweight fill. There is approximately a one-third reduction in both settlement and piles when common fill is replaced by lightweight fill. The lateral earth pressures developed in the LWA will be about one-half the pressure of sand fill and less than one-half the pressure developed in common fill.

The final analysis in this case study was a cost comparison. The cost of the common fill, compaction, and piles are from the 1990 Means Site Work Cost Data publication. The costs used were $5-10/cu yd for common fill, $20-25/ft with a $6,000 mobilization for piles, and $23.75/cu yd for LWA. The cost of compaction for LWA would be less than that for common fill because it is more easily compacted, but this is not taken into account in this scenario. Three scenarios are given for the cost outcome:

- In the first, the cost savings would be between 30 to 50% for using LWA as fill, if the lower costs for the fill and piles are used and piles are not used in conjunction with the lightweight fill.
- In the second scenario, the common fill embankment is about 20 to 30% less expensive when the lower cost for fill and piles are used and piles are used with the lightweight fill.
- In the third, the costs are about the same when the higher cost for fill and piles are used and piles are used with the lightweight fill. Essentially, the real savings in this case are when the need for piles is eliminated through the use of lightweight fill.

The paper (Brettmann, 1991) does not indicate whether the embankment was constructed with lightweight fill or not, but the case study does provide a good comparison between lightweight and common fill for a particular application.

A second study by Holm and Valsangkar (1993) gives a brief formula for justification of the expense of LWA over common fill. They point out that while LWA tends to be more expensive on a price per ton basis, "because of the significantly lower bulk density, a fixed weight of this material will obviously provide a greater volume" and offset the price difference to some extent. The formula [$(X+Y) x 60 x 27]/2,000 gives an in-place, compacted moist density material cost for LWA in $/cu yd, where X is the price per ton, Y is FOB (freight on board) the production plant and trucking costs to the project location per ton. The conversion of the price per cubic yard provides a fairer price comparison to common fill. This price, however, does not include compaction cost which, as discussed above, is lower for LWA.

In the lower 48 states, the common method for obtaining LWAs is ordering them from a manufacturing plant. Brian Rockers, a sales representative for Buildex, Inc., (a LWA distributor in Ottawa, Kansas) was contacted in June 2002. He quoted a cost of $232.63 per cubic yard for on-site delivery of LWA. The cost broke down to a $22.25 per cubic yard price and $210.38 per cubic yard (approximately $467.50 per net ton) for trucking freight. The gradation requested was 3 /4 in. (19 mm) to #4 sieve size (4.75 mm). This price quote demonstrates the impracticality of shipping the aggregate to Alaska, especially with most of the LWA manufacturing plants centered in the Midwest and East Coast areas.

5- Manufacturing Lightweight Aggregates

The cost quote from Buildex Inc. (Rockers, 2002) shows the importance of Alaska in developing its own manufacturing method for LWAs in order for their use to be feasible. Clearly LWAs will only be a cost-effective solution with Alaskan manufacturers, either private or state sponsored.

Two literature sources related to manufacturing of LWAs were found:

- The first is a Texas A&M report titled “Studies of the Thermal Transformation of Synthetic Aggregates Produced in a Rotary Kiln” by Houston et al. (1969). This study investigated a process for determining the optimum combination of temperature and retention time for developing LWAs in a rotary kiln. It studied the effect of a rotary kiln’s retention time and temperature on the degree of transformation occurring in clay. The methods used included X-ray diffraction, differential thermal analysis, effluent gas analysis, and gas chromatography. The authors stressed the need for continued study of the process of manufacturing LWAs and concluded that temperature and retention time are important parameters with an optimum unique to each particular raw material.

- The second report is titled “Investigations of Lightweight Aggregates in Alaska”, by Heiner and Loskamp (1966). The study investigated the characteristics of several shale deposits near Fairbanks and Anchorage, Alaska, to determine their quality for use in the manufacturing of LWAs. The study presented a list of desirable mineral deposit and resulting aggregate properties: “uniform deposit chemically, crushing not to produce in excess of 20% minus eight mesh fines, bloating temperature between 1800 - 2300 ^{o}F (980 - 1300^{o}C), wide range of bloating, bulk density of aggregate between 45 - 75 pcf (720 - 1200 kg/m^3), [and] absorption between 0-18%”.

The study presented some geographic and geologic properties of raw material deposits that help insure low production costs in LWA manufacturing: “location close to market, presence of proper transportation facilities such as railroads and highways, presence of cheap fuel, sufficient size of deposit to insure several years production, thin overburden, [and] location above groundwater or presence of proper conditions for a drain”.

Four shale deposits located near Fairbanks and four near Anchorage were investigated as possible sources for LWA production. All of the deposits were located along the highway or Alaska Railroad. The aggregate testing was patterned after procedures published by the U.S. Bureau of Mines, I. C. No. 8122. These procedures had been used by consulting firms and the Bureau of Mines as “criteria for advancing shales for further testing in rotary kilns”. The laboratory tests included “drying characteristics, crushing characteristics, pelletizing characteristics, slow-fire characteristics, expansion properties, bleb structure, concrete strength, [and] concrete thermal conductivity”. The deposits showing the most promise for production of LWA were:

- the shale deposits at 44.7 and 59 mile on the Elliott Highway between Fairbanks and Livengood,
- the Sutton shale taken from the road cut at Mile 16 on the Sutton Subdivision of the Alaska Railroad, and
- the Kings River shale taken from a road cut, 67 miles (110 km) northeast of Anchorage, on the Glenn Highway.

The authors recommend these shales for systematic sampling and testing under commercial conditions.

Heiner and Loskamp (1966), of the University of Alaska’s Mineral Industry Research Laboratory, are not the only Alaskan researchers to have examined Alaskan deposits for their LWA potential. The U.S. Geological Survey completed a study on the suitability of Alaskan minerals for construction aggregate use in 1959, as did the U.S. Bureau of Mines in 1953 and 1962. The U.S. Geological Survey concurred with Heiner and Loskamp (1966) on the suitability of shales from Kings River and Sutton deposits for LWA production, and also recommended the shale from the Lawing area, which is on the Seward Highway.

A second question to consider in the manufacturing of LWAs is whether to use the rotary kiln or the traveling grate process. As discussed earlier, the rotary kiln has the “advantage of production of a uniform coated aggregate with low water absorption characteristics” (Heiner and Loskamp, 1966). In addition, maintenance costs are generally low and operating reliability high for the rotary kiln. However, the disadvantages are that “fewer raw materials can be satisfactorily processed [because coated aggregate requires closely sized shale particles for production]; the initial cost of a kiln (and the installation cost) is usually high; unless properly designed and furnished with heat recuperating devices and a good cooler, the fuel consumption of a rotary kiln can be quite high; the space requirement of a rotary kiln is usually greater than that of a traveling grate; [and] the feed size range to a rotary kiln usually must be quite narrow”. However, “grate products generally suffer from high water absorption, poor quality control, and the grate method has high maintenance cost and high power consumption”.

6- Conclusions

Lightweight aggregates have become an accepted construction material and continue to be an area of active research. These aggregates, created from expanded shale, clay, and slate, have shown their value through their low thermal conductivity, low unit weight, and high internal angle of friction, among other properties. Lightweight aggregates are most commonly used in lightweight concrete and as lightweight fill, however, use in highways as insulation and embankment material is being developed and tested in some places in the U.S. and especially in Norway, Finland, and Sweden. In fact, although using expanded clay has not become a design standard in the Nordic countries, it is in limited use. Their research and testing is especially valuable to Alaskans considering lightweight aggregate testing, because of the similar climates and resulting highway problems, such as frost heave and decreased bearing capacity during spring thaw. Although the Nordic lightweight aggregate research does not directly deal with permafrost issues, lightweight aggregates insulating capabilities and low unit weight show promise for this problem area.

In Alaska, cost of currently available materials is obviously prohibitive when it comes to shipping lightweight aggregates from manufacturing plants in the lower 48. In addition, availability of preliminarily tested shale deposits along Alaskan highways and railroads makes manufacturing lightweight aggregates in Alaska an attractive option. There will also be a cost associated with developing this industry and learning how to effectively apply lightweight aggregates to Alaskan roads. However, when lightweight aggregate is used in road embankments or as insulation layers, there is the promise of a significantly reduced maintenance costs, as well as better highways. In addition, cost may be decreased because the road thickness may be decreased when a layer of lightweight aggregate is used for insulation to protect the permafrost.

While lightweight aggregate appears to be a promising highway material, the final question to ask is whether the benefits of its use outweigh the increase in cost. This cannot be conclusively answered without constructing experimental road segments, where lightweight aggregates layers of variable thickness and depth from the pavement surface are incorporated in experimental roadways, instrumented and monitored over time to capture their behavior in the Alaskan harsh conditions.

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