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# Design of specific gravity factor of artificial lightweight aggregate

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The aim of this paper is to obtain the thermal treated (modified) waste expanded polystyrene aggregates (MEPS) utility as a concrete aggregate and for mix design of concrete feasibility necessary specific gravity factor (SGF). A series of experiments are carried out to determine the SGF of MEPS. The value so determined is not an actual specific gravity but is only a factor. This factor may, however, be used in subsequent calculations as though it is the apparent specific gravity, using the principles of absolute volumes, so long as the moisture content and density of the aggregates remains unchanged. In this study, the cement dosages for concrete mixes are 400 and 500 kg/m$^3$. The targeted ultimate compressive strength would be 8.0 MPa. Pre-wetted aggregate is used. The resulting concretes are seen to have densities varying from 800 to 1000 kg/m$^3$, with the corresponding strengths varying from 5 to 8 MPa. The experimental results indicate that the SGF of MEPS aggregates for 400 kg cement dosage's concretes are 0.22 and 0.31, and for 500 kg cement dosage's concretes are 0.24 and 0.34, respectively, for coarse and fine aggregates.

**Keywords:** Specific gravity factor, Modified waste EPS aggregate, Lightweight aggregate

Civil construction is growing rapidly in Erzurum, Turkey because of the Universiade 2011 Winter Games and the demand for aggregates increase day to day. Nevertheless, environmental considerations hinder the supply of natural aggregate. Moreover, there are strong objections to opening of pits as well as to quarrying because of the ski area.

Nowadays, industrial activities generate a huge amount of waste. Concrete is the most widely used substance apart from water. Aggregate used in concrete is dependent on availability. In view of sustainable development, the use of other sources of concrete components has acquired particular interest in construction industry[1].

Therefore, the production and the use of artificial aggregates become necessary. There are different sources of artificial lightweight aggregate that can be produced from a wide variety of raw materials and production procedures. The properties and the characteristics of lightweight aggregates vary within wide limits[2]. Expanded polystyrene foams (EPS) is currently used as a popular packaging or insulating material in various industrial fields in the world. A large quantity of EPS is consumed, and is disposed as a waste. Effective recycling countermeasures against the waste EPS are strongly requested. For these reasons, a part of this study has been conducted through basic experimental research in order to analyze the possibilities of modifying and recycling of waste EPS as aggregates for concrete. Kan and Demirboga[3] have studied on concrete composites and suggested that EPS provide an unconventional method for reducing concrete density. Traditionally, EPS aggregate has not been used in structural concrete due to low strength but the literature suggests that thermal modification can dramatically increase the strength of concrete produced with these aggregates. This process requires the waste foam to be exposed to 130°C temperatures for 15 min[3]. The results of testing on EPS aggregate concrete have shown that even at high levels of replacement it is still has sufficient strength to be utilised in semi-structural members.

It is well known that the strength properties of concrete and mortars are closely related to the density and volume fraction of aggregate[4]. The quality of concrete depends on used aggregate, where "quality" is expressed in terms of aggregate specific gravity (SG) or specific gravity factor (SGF). The SGF, the ratio of the weight of aggregates, including all moisture, as introduced into the mixer to the effective volume displaced by the aggregates.

Production of lightweight concrete is more difficult than normal-weight concrete because the aggregates vary in absorption of water, specific gravity, moisture

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content, and amount of grading of undersize. An analysis of the present tendencies in worldwide building activities shows that in design and construction of buildings of the next generation, specialists will make substantial efforts to minimize the weight of buildings[5].

Specific gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. Water at a temperature of 23°C has a specific gravity of 1.00. Specific gravity is important for several reasons. Some deleterious particles are lighter than the good aggregates. Tracking specific gravity can sometimes indicate a change of material or possible contamination. Differences in specific gravity can be used during production to separate the bad particles from the good using a heavy media liquid[6].

Aggregate classified by density or specific gravity are classified into three categories: Lightweight aggregates, normal weight aggregates and heavyweight aggregates. The most commonly used type in concrete are normal weight aggregates which generally range in density from about 2.45 to 2.90. Lightweight aggregates' density are generally below 2.0 and are widely used in lightweight concrete where weight is a critical factor in the design considerations of a structure. Density is one of the important parameters, which can control many physical properties of lightweight concrete. It is mainly controlled by the amount and density of lightweight aggregate. Heavyweight aggregates are used in concrete to increase the weight of the concrete or to provide shielding in concrete for nuclear power plants. Heavyweight aggregates' density range from about 3.0 to 5.0[7].

Due to their cellular structure, bulk specific gravity (BSG) of lightweight aggregates is lower than that of normal weight aggregates. The BSG of lightweight aggregates also varies with particle size, being highest for fine particles and lowest for coarse particles. This is because crushing destroys larger voids, producing finer aggregates with lower porosity. With present ASTM methods (ASTM C 29[8], ASTM C 128-04[9], ASTM C 330-04[10]), it is difficult to determine BSG and absorption for lightweight aggregates accurately, due to problems in consistently achieving a saturated surface-dry state (SSD). Thus, in designing concretes using lightweight aggregates, a SGF is used instead of the BSG. This factor is found in the same way as the BSG, SSD previously described except that Mass "S" is the mass of the aggregate at the stockpile moisture, and the mass of the sample in water is measured at a specified number of minutes after immersion. For this, instead of specific gravity of aggregate, SGF concept developed in different moisture conditions. SGF, as can be found both with Pycnometer method and directly from the trial mixture. According to the 211.2[11], the weight (pycnometer) method uses ACI determined by a displacement pycnometer test on the aggregates (Method 1). Weight method also employs the SGF to estimate the weight per $m^3$ of the fresh concrete. The damp loose volume method uses the cement content-strength relationship for the design of all lightweight and sand lightweight concretes (Method 2). Additional information of SGF for lightweight aggregates is given in the Appendix of ACI 211.2[11]. The particular properties of lightweight aggregate pose special problems in calculating proportion for lightweight concrete. As a result, the absolute volume method cannot be used with the same confidence for lightweight concrete, because of the variations in BSG and water absorption.

By eliminating the need for all subsequent collection and disposal, this waste management system offers significantly superior cost saving, convenience and direct environmental effectiveness than any known alternative.

## Experimental Procedure

### Materials

Several experimental studies are carried out on concrete specimens according to Turkish and European codes. The properties of materials used in concrete mixtures are given below. ASTM Type II, Portland cement (PC) was used in this study. MEPS aggregates, waste EPS foam from vocational college of Erzurum laboratories were obtained[3]. Fresh clean tap water was used throughout the study, which was at 20ºC.

### Method

The specific gravity and water absorption of lightweight aggregate were tested according to ASTM C330[10] and C567[12]. The size distribution was measured according to ASTM C136[13]. MEPS aggregates were wetted initially with a part of the mixing water before adding the remaining materials. In other words, the aggregate was pre-wetted with one third of the mixing water with the assumption that the aggregate would be 'surface- saturated' prior to mixing. Concrete was mixed in a planetary mixer of 100 L capacity. Mixing was continued until a uniform and flowing mixture was obtained. During casting, all of the specimens were compacted by rotting. The fresh concrete densities and slump values were

measured immediately after the mixing. The slump varied between 40 and 50 mm and facilitated hand compaction. During the first 72 h, the specimens were left in the moulds. The specimens were cured under wet gunny bags initially and, then the specimens were removed and cured in water (25± 2$^{o}$C) until the time of testing. The compressive strength of aggregate was obtained from research on waste expanded polystyrene foams[3]. At 28 days, the compressive strengths were tested according to ASTM C 39[14]. Prior to the tests, specimens were removed from the curing room and left to dry in air for 24 h. The target 28-day cylinder compressive strength for both types of concrete mixes was 5 to 8 MPa.

Trial mixes were cast to determine relations between strength and cement dosage. For this reason, 400 and 500 kg/m$^3$ dosage mixtures were prepared. In the prepared concrete and targeted strength values to obtain consistency, the mixture of the SGF because of the account value, it will be accepted as the value of the aggregate group. The proportion of the various trial mixes can be related to the first mix of satisfactory workability, using a so-called SGF, which is a ratio of the weight of the dry aggregate to the space occupied by it. This space is the volume of concrete less the absolute volume of the cement and less the volume of water, including that the difference between a SGF and the actual specific gravity lies; but for a given aggregate in a given moisture condition the volume of water absorbed during mixing is approximately constant. Thus, the SGF can be used as if it were the actual specific gravity. The factor has, of course, a different value for fine and coarse aggregate[15].

Method 1: This method utilizes the fact that the sum of the weights per unit volume of all ingredients in a mixture is equal to the total weight of the same mixture. If the weight of the particular concrete per unit volume, which contains a particular aggregate, is known or can be estimated from the specific gravity factor of the aggregate, the weight of the lightweight aggregates in that volume of concrete can be determined.

Method 2 is Absolute volumetric method. When trial mixtures are proportioned by procedures other than the weight method (i.e., Method 1 specific gravity pycnometer), the net water-cement ratio of most lightweight concrete mixtures cannot be established with sufficient accuracy to be used as a basis for mixture proportioning. This is due to the difficulty of determining how much of the total water is absorbed by the aggregate and is thus not available for reaction with the cement, versus the amount of water that is absorbed in open surface pores or cells of the aggregate particles, which usually remains there after surface drying and is available to react with the cement[16]. The amount of free water in the surface pores or open cells varies according to the size and number of pores or open cells in the lightweight aggregate particles. Lightweight aggregate concrete mixtures are usually established by trial mixtures proportioned on a cement air content basis at the required consistency rather than on a water-cement ratio strength basis when the weight method is not employed[11].

**Design and calculation of SGF**

The initial fine aggregate content is based on the estimated weight of cubic meter of concrete. This depends on the relative density of the lightweight coarse aggregate, which is expressed in term of an approximation of the bulk specific gravity as the specific gravity factor (SGF) 10. The SGF is defined as,

$$SGF = \frac{\text{weight of aggregates}}{\text{effective volume of aggregates}} \quad \ldots (1)$$

SGF is dimensionless. SGF is not a true specific gravity, since its value incorporates compensation for absorption of free water by the aggregates, but it is used in exactly the same way to calculate volume relationship. The SGF, which can be determined for lightweight fine as well as coarse aggregates, depends on the initial moisture content of aggregate.

**Designing trial batch of the MEPS aggregates**

To determine of SGF for 400 and 500 dosages mixture of MEPS aggregates required concrete mix design was made following the guidelines reported by Newille[15], Mindess [17] and Jackson[18]. The results are given in Table 1. The gradation of MEPS aggregates was determined based on the Turkish Standards 2511[19] method. Usually to get 1.000 m$^3$ of concrete, between 1.100 and 1.200 m$^3$ lightweight aggregate is required. Based on experience with these materials, the total volume of damp loose aggregate per m$^3$ of concrete will be taken as 1.150 m$^3$, consisting of 0.690 m$^3$ coarse MEPS aggregate and 0.460 m$^3$ of fine MEPS aggregate. In this stage, 400 and 500 kg of cement in a mixture of 1 m$^3$ respectively and 0.35 water/cement ratio was adopted. No air entraining chemicals or mineral admixtures were used in any tests. In most cases, the target fresh mixture properties

Table 1 – Estimation of first trial batch using the absolute volumetric method (cement contents 400 and 500 kg/m$^3$ and w/c=0.35)

| | First trial batch Weights, damp, loose (kg) | Effective displaced volume (dm$^3$) | Adjusted weights damp, loose (kg/m$^3$) |
|---|---|---|---|
| Cement | 400 | 400/3.05=131.15 | 400/1.150=347.83 |
| Air (1%) | - | 10.00 | |
| Added water (50 mm slump) | 400x0.35=140 | 140/1.00=140 | 140/1.150=121.74 |
| Total volume (without MEPS aggregate) | - | =281.15 | - |
| Volume of MEPS aggregate | | 1000-281.14=718.85 | - |
| Coarse MEPS aggregate | 0.60x1150x0.138=95.22 | 431.31 | 72 |
| Fine MEPS aggregate | 0.40x1150x0.191=87.86 | 287.54 | 66.43 |
| actual unit weight (for 400 dosage) | 723.08 | 1000 | |
| Cement | 500 | 500/3.05=163,93 | 500/1.150=434.78 |
| Air (1%) | - | 10.00 | |
| Added water (50 mm slump) | 500x0.35=175 | 175/1.00=175 | 175/1.150=152.17 |
| Total volume (without MEPS aggregate) | - | =348.93 | - |
| Volume of MEPS aggregate | | 1000-348.93=651.07 | - |
| Coarse MEPS aggregate | 0.60x1150x0.138=95.22 | 390.64 | 72 |
| Fine MEPS aggregate | 0.40x1150x0.191=87.86 | 260.43 | 66.43 |
| Actual unit weight (for 500 dosage) | 858.08 | 1000 | 725.39 |

were a slump of 40 to 50 mm and an air content of 1.0%. 1 m$^3$ of concrete mixture, was calculated to be 1.150 m$^3$ MEPS aggregates.

Acceptable entrapped air content is 1.0%.

Mass density of cement PKÇ II/B-M 32.5R =3.05 kg/dm$^3$

Dry loose density of coarse MEPS aggregate =138 kg/m$^3$

Dry loose density of fine MEPS aggregate =191 kg/m$^3$

Total moisture content of MEPS aggregate: = 0%

After mixing, the actual unit weight of the trial batch is 723.8 kg/m$^3$ for 400 and 858.08 kg/m$^3$ for 500 dosages. Based on these values (Table 1), according to the trial of concretes, workability, consistency and strength properties, validity of SGF will be proven. In the above computations, the specific gravity of water is always assumed 1.0 and the density at 1.0 g/cm$^3$.

The calculation of SGF for the concrete 400 kg/m$^3$ of cement from Eq. (1):

$$\text{Coarse aggregate, SGF} = \frac{95.22}{718.85 \text{ X } 0.60} = 0.22$$

$$\text{Fine aggregate, SGF} = \frac{87.86}{718.85 \ X \ 0.40} = 0.31$$

The calculation of SGF for the concrete 500 kg/m$^3$ of cement

$$\text{For the coarse aggregate, SGF} = \frac{95.22}{651.07 \ X \ 0.60} = 0.24$$

$$\text{For the fine aggregate, SGF} = \frac{87.86}{651.07 \text{ X } 0.40} = 0.34$$

**Results and Discussion**

The essential characteristic of MEPS is its high internal porosity, which results in a low apparent specific gravity. Since the lightweight particles of coarse aggregate are relatively weak, their strength may be the limiting factor affecting concrete strength[20]. It cannot contribute to the concrete strength. Kan *et al*.[21] has pointed out that compressive strength of EPS foam is very low. However, after the waste EPS foams have been modified, compressive strengths was developed. The compressive strength of the original waste EPS foams was changed between 0.068 and 0.39 MPa[21]. MEPS aggregate's compressive strength at 10% deformation was changed from 1.75 to 8.29 MPa after the heat treatment[3]. MEPS aggregates are polymer origin. Moreover, its humidity rate is zero. Concretes was prepared for the determination of SGF, have the ability to become the first concrete made with aggregates MEPS. We obtained the great experience about behaviour of MEPS aggregate in the concrete mix. For example, the setting time of the MEPS concretes has been extending. For this reason, like normal aggregate concrete after 24 h moulding was not kept in curing

Table 2 – Compressive strength and other properties of SGF concretes samples

| Dosage | Specific gravity factor (SGF) | | w/c | Fresh | Hardened (28 days) | Measured | Target | Meas | Targ. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Concrete density (kg/dm$^3$) | | Compressive strength at 28 days (MPa) | | Slump (mm) | |
| 400 | Coarse<br>Fine | 0.22<br>0.31 | 0.35 | 0.877 | 0.863 | 5.0 | 5.0 | 30-50 | |
| 500 | Coarse<br>Fine | 0.24<br>0.34 | 0.35 | 0.981 | 0.940 | 8.20 | 8.0 | 40-50 | |

tank. The setting time can be delayed either by the surrounding environment or by additions to the concrete, which affect the chemical reactions. It has been shown by Justnes *et al.*[22] that setting time of concretes increased with an increased w/c ratio.

Before the heat treatment, the average density of unmodified waste EPS foams was 10-50 kg/m$^3$. After the modification[3], density of MEPS, increased to 217 kg/m$^3$. MEPS aggregate concrete mix design was based on SGF; w/c ratio and aggregate properties were remained the same.

For the determination of SGF trial concrete was cast. Results showed that sufficient density, slump and strength were observed as shown in Table 2. At the end of the unit weight tests on the fresh and hardened concretes, it was seen that unit weight decreases when the dosage decreases. Values obtained from the series by slump test are given in Table 2. As seen from the table, SGF and density affect aggregate size. 28-day compressive strength of SGF of 500 cement dosage concrete was slightly higher (by 6%) than that of predicted values.

It can be concluded that calculated SGF values are valid and mix design lightweight MEPS concrete can be done by SGF without hesitation.

The reason for this an amount of aggregate volume (approximately 25%) with pre-wetted lightweight aggregate replacement, in the concrete to create that providing a source of continuously water curing and the aggregate pre-wetted as a result of participation, less autogenous shrinkage of the concrete can be achieved. Setting times of concrete made with pre-wetted MEPS aggregate was retarded more than that of dry surface aggregate. Pre-wetted aggregate often has a retarding action. According to the Lo *et al.*[23], like other porous materials, water absorption of the lightweight aggregate is usually higher than that of normal aggregates. Micro cracking at the interface will easily appear at early hydration due to higher absorption rate. Pre-wetting the lightweight aggregate



Fig.1 – The position of the MEPS aggregate concrete cylinders in the curing tank

is one method of minimising the effect and therefore maintaining the consistency of the concrete mix.

Density of MEPS concrete was found to be lower from density of water. MEPS concrete samples are placed in a wire basket suspended in water for curing. Otherwise, as shown in Fig. 1 all samples were swimming on the curing tank.

These observations indicate that the SGF properties of the MEPS mostly depend on the aggregate properties and are so much influenced by the matrix composition. Qualities of MEPS aggregate such as its SG, shape of particles of and grading can be controlled in its producing process, and these factors will have important effect on the quality of structural lightweight concrete.

## Conclusions

SGF, which is an important aggregate property, may change significantly in aggregate of origins. Results showed that sufficient unit weight, workability and strength of concrete were produced by SGF method. It can be concluded that calculated

SGF values are valid and mix design of lightweight MEPS can be done by SGF without hesitation. SGF for 400-dosage concrete were 0.22 and 0.31, and 500-dosage concrete were 0.24, 0.34 for coarse and fine aggregates, respectively. SGF, different from the specific gravity, but it can be used in mix design like those that a specific gravity is a numeric size. The SGF can be used as if it were the actual specific gravity. The SGF is calculated as the relationship between the dry weight of the aggregate in the mix and the displaced volume it is assumed to occupy. The value so determined is not an actual specific gravity but is only a factor. The values we obtained show that we can use MEPS if it is necessary. In addition, it is necessary to calculate the waste aggregate lightweight concretes before using them in producing concrete.

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