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Improving The Strength Characteristics of The Pumice Aggregate Lightweight Concretes

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ABSTRACT: Lightweight concrete is commonly used in civil engineering field, specially as a filler material or for the manufacture of heat and sound insulating units, as well as load bearing structural elements. In most industrialised countries, lightweight concrete production is performed by using a highly mechanised processes based on different automation techniques. Various artificial and natural porous aggregates are generally used in these types of concretes. The most popular among them are ceramsite, slag pumice, ash gravel, expanded perlite, volcanic slag, pumice, vermiculite etc. All the porous aggregates have their own characteristic properties, which markedly affect the properties of lightweight concretes. Among the lightweight concretes, pumice concrete was generally considered as being unsuitable for load bearing uses. For this reason, it has been mainly used for the production of partitions and panel walls. Strength requirements for building blocks are most commonly set at 2.5 MPa for filler blocks and 5.0 MPa for load bearing blocks. In general cases, the effects of admixtures, such as crushed gravel, tly ash and limestone powder, in lightweight aggregate mixes are not known very well. Therefore, the admixture types, affecting the compressive strength of a mixture should be determined by a series of experimental test works. In this paper, many investigations were carried out in order to obtain maximum compressibility of lightweight concretes by using several additional mixes and admixtures.

I INTRODUCTION

Pumice stone is a very popular raw material as a lightweight rock, due to having a desired properties for making the different products based on its physical, chemical and mechanical properties. For this reason, it has a large using area in civil industry as a construction material and it has been used for centuries in the world. Pumice aggregate can be found in many places around the world where volcanoes have been present.

Pumice aggregates combined with Portland cement and water produces a lightweight thermal and sound insulating, fire-resistant lightweight concrete for roof decks, lightweight floor fills, insulating structural floor decks, curtain wall system, either prefabricated or in-situ, pumice aggregate masonry blocks and a variety of other permanent insulating applications.

It is a common practice to classify lightweight concrete into three categories. These are insulating concrete, intermediate concrete and constructional concrete. This classification is based on unit weights, and integrates between types and uses of aggregates. All the research studies, carried out to analyse the performance of the lightweight pumice concrete for stability and durability conditions, have showed that these concrete types could be achieved with pumice aggregates.

It has been stated that, despite the different properties of porous aggregates, lightweight concretes have some common regularities and properties. Lightweight aggregates generally have an enormous advantage in comparison to natural aggregates due to their structural pores and their consistent properties (Kornev et.al. 1980).

From these aggregates, pumice is a lightweight, porous effusive rock, with an extremely vacuolated structure, and closed pores due to the formation of gaseous bubbles during the rapid cooling and consolidation of the magma (Failla et.al. 1997).

2 PUMICE AGGREGATES IN THE CONCRETE

Pumice is a well known lightweight concrete aggregate, although its use has mainly been restricted to dry mixes such as for block making and masonry use. There are both advantages and drawbacks connected with the material as an aggregate. Its compressive strength is low, between 5 and 7 MPa for usual pumice material of normal gradation. Therefore, high strength constructional concrete is not to be expected. However, the relation between weight and strength may be favourable for pumice concrete, and the ease of handling, insulating qualities and other properties then make it advantageous.

The surface texture of pumice is such that their concrete types require more binding media than if they were made of smooth or glazed surface aggregates. The abrasive nature causes a define stiffness in lean concrete, which may be an advantage in mixes for block making since it causes less breakdown of the products in production. On the other hand, some of the binding media enters into the pumice surface and more of the binding media is required, which increases costs of production. In rich concrete the dense cement paste imparts the drying of the aggregates.

3 LIGHTWEIGHT AGGREGATE CONCRETE

Lightweight concrete is a broad term covering concrete made with a wide variety of aggregates, both natural and artificial. Lightweight concrete already plays an important role in .structural engineering and its use is steadily increasing. The predominant feature of a structural material is, no doubt, its compressive strength. With the modern trend towards taller structures and longer spans, there is a growing demand for stronger concrete. Lightweight concretes are cement-bonded products. Therefore, it is not surprising that many of the common properties as development of strength, drying shrinkage, bond to reinforcement etc. are very much influenced by the properties of the cement or the "binder matrix" used. It has been found that, a new binder composition makes it possible to produce a stronger lightweight concretes. To achieve the strength and quality required for high strength lightweight aggregate concrete needs a higher proportion of cement content in the mixture than dense concrete and mostly replacement of lightweight fines by sand (Bürge, 1983).

Lightweight concrete is generally a concrete with specific gravity 800-1800 kg/nr\ Specific gravity can be lowered either by using porous, therefore light, aggregates instead of ordinary ones, or introducing air into the mortar, or removing the fine fractions of aggregate, and compacting concrete only partially. In all cases, the main aim is to introduce voids into the aggregate into the mortar or between mortar and aggregate. A combination of the three methods can also be made in order to reduce furtherly the weight of concrete. The use of lightweight aggregates is by far the simplest and most commonly used method of making a lightweight concrete and pumice is the most widely used lightweight aggregate especially for lightweight structural concretes. The specific gravity of the concrete is about to 900 - 1600 kg/m^1.

Structural lightweight aggregate concretes are considered as alternatives to concretes made with dense natural aggregates because of the relatively high strength to unit weight ratio that can be achieved (Bomhard, 1980).

Other reasons for choosing lightweight concrete as a construction material are becoming increasingly important as more attention is being paid to energy conservation and to the use of waste materials to replace exhaustible natural sources. For example, the thermal resistance of such materials increases with the decreasing density and this ensures considerable amount of energy savings (Newman andBremner, 1980).

Strength of coarse aggregate for constructive lightweight concretes is always considerably lower than that for mortar component. Therefore, under force actions their destruction takes place in grains and interlayer of mortar rather than due to adhesion rupture between aggregates and mortar as in heavy concrete. Adhesion between aggregates and matrix is considerably higher than that in dense aggregates that is not only the effect of porous rough surface of granules, but also physicochemical influence of hardened cement paste and aggregates due to self vacuum treatment, strengthening of contact zone as well as formation of new hydrated compounds. All these processes, proceeding during lightweight concretes hardening, affect positively the adhesion between aggregates and mortar and also bond between tendons and concretes.

Positive factor in lightweight concretes is also the "compatibility" of elastic properties for porous aggregate and mortar as strength and elastic modulus of aggregates in heavy concretes are several times higher than those of mortar. Therefore, concentration of stresses on the boundary of porous aggregates and cement mortar decreases and as a consequence, there increase the stresses corresponding to the boundary of micro cracks formation and to creep transition from linear to non-linear one.

in connection with the fact that porous aggregates have rather low elastic modulus, most types of lightweight concretes as compared to heavy ones, have non-elastic (plastic) strains both in compression and tension, it is explained by higher brittleness of lightweight concretes. Figure 1 shows typical stress-strain diagrams under compression of lightweight and heavy concretes.

In lightweight concrete, coating with uniform bonds throughout the surface of aggregate granules is created in contact zone between mortar and aggregate due to absence of water film because of suction of chemically uncombined water by aggregate. This develops a higher adhesion between porous aggregate and mortar and promotes decrease of plastic strains.

Lightweight concretes have high shrinkage that is the cause of low elastic modulus of porous aggregates. In connection with this shrinkage of lightweight concretes is, as a rule, 1.3-2 times higher than that ia heavy concrete depending on the sort of coarse and fine aggregate (Kornev et.al., 1980). Maximum compressibility of lightweight concretes is considerably higher than that in heavy concrete. The simplified example of this is given in Figure 2. It is determined by the fact that elastic modulus of lightweight concrete are markedly lower than those of heavy concrete. Although plastic strains of heavy concrete are comparatively high, but they do not compensate higher elastic strains of lightweight concretes. High maximum compressibility of lightweight concretes affects positively on the strength of pre-stressed members (Kornev et al., 1980).

4 STRENGTH OF LIGHTWEIGHT PUMICE CONCRETES

There are several considerations that limit the maximum strength of high strength lightweight aggregate concrete. The decisive factor is the individual particle strength of the largest pieces of lightweight aggregate. Each particular material has a limiting strength "ceiling" beyond which there can be no appreciable strength gain despite large increases in cementitious materials. This strength "ceiling" is a function of the strength of the vitreous material and the quantity, size, shape and distribution of the envelope pores. All coarse aggregates have continuous gradations of low inter particle void content that requires a minimum amount of cementitious mortar to achieve salısfactory workabi 1 ity.

The influence of the top size of coarse lightweight aggregate on ultimate compressive strength was analysed by several investigations in which the effects of other variables were minimized. For this particular material, maximum achievable strength occurs when the aggregate top size is limited to approximately 10-15 mm.

Long term strength gain of the structural lightweight concrete was generally greater than the conventional concretes due to the continuous hydration of the binder with the slowly released moisture, resulting from water absorbed within the pores of the lightweight aggregate. This process of "internal curing" is possible when the moisture content of the lightweight aggregate at the time of mixing is at least equal to that achieved by soaking for one day (Holm, 1980).

According to the principles of rock mechanics, the experimental research findings related with the technical properties of lightweight concrete were evaluated and defined in detail in order of importance. The strength of concrete generally show a variation with the function of the rock components, water/solid ratio and cement dosage used in concrete mixture. For this reason, the strength value of the mixture is generally defined with the value after a period of 28 days curing time. In general applications, the strength of the concrete after 28 days can be acquired by the way of determining the uniaxial compressive strength of the standard concrete samples. In addition, especially in excessive stress conditions, the critical stress value with the unit elongation or strain must be investigated in detail.

4.1 Mechanical Characteristics

Lightweight concrete compression tests show that the breakage occurs in the aggregates not in the cement paste. Consequently, grain resistance to crushing is extremely important in lightweight concrete. The various methods are used to measure this parameter. Some specifications suggest an empirical method whereby 1 litre of aggregate is compressed into an 11,3 cm diameter and 18 cm high cylinder, by a piston which penetrates into the cylinder by 20 mm in 100 seconds. The load bearing on the piston, divided by its surface area represents the resistance to crushing of the sample grains. This test carried out on pumice aggregates resulted in a 24,5 kg/cm^2 crushing resistance.

So as to avoid a low-resistance, high deformation lightweight concrete, an acceptable quality mortar must be employed. This calls for the use of a type of sand which unlike pumice, shows good resistance characteristics. Shore or crushed sand may be used to totally or partially replace the lightweight aggregate (size up to 3 mm). More specifically, shore sand was used instead of the lightweight aggregate in the 0-0,5 mm range and crushed sand was used instead of the lightweight aggregate in the up to 3mm range in the batches (FailIa et al, 1997).

4.2 Aggregate pre-soaking

Lightweight concrete characteristics generally depend on the aggregate water content prior to mixing. Excessive water content causes lack ot adherence between the aggregate and mortar, while low aggregate water content causes the aggregate to soak up part of the mortar water, thus causing a cement sub-hydration and consequent reduction of the concrete shape alteration capacity. Both cases result in lower resistance characteristics than when the aggregates are moderately soaked just prior to concrete preparation. The pre-soaking time chosen for pumice aggregates (30 minutes) has shown to give the best results as to resistance and workability characteristics (Failla et al, 1997).

4J Compression Resistance

Lightweight conglomerates subjected to compression behave differently from ordinary conglomerates. While in the latter case, stresses propagate from aggregate to aggregate, in the former they propagate through the mortar matrix, which is much Stifter than the aggregates that it contains. Thus, in general, if the quantity and the quality of the inortar in a lightweight concrete is increased, the resistance of the inortar structure is enhanced and consequently the conglomerate compression resistance is also increased. On the other hand, mortar content in lightweight concrete should not be increased excessively so as not to result in a net increase of the conglomerate mass volume as well as avoiding the rising to the surface of the larger grains during mixing (Failla et al, 1997).

The cement mortar content to be used in the manufacture of acceptable resistance lightweight concrete should be 50-60 % by volume. These limitations were observed in the preparation of pumice concrete. As previously mentioned above, fine pumice (0-3 mm) in the aggregate was replaced so as to increase mortar quality and therefore concrete resistance and workability. This fact has resulted in a noticeable increase in the 28 day compression resistance. Comparing the results of the tests of the various mixes, one may observe that the resistance characteristics are also greatly influenced by the nature and screen size of the sand. In general, lightweight concrete shows a rapid initial hardening with a parallel noticeable increase in compression resistance. In actual fact, lightweight concrete achieves approximately 80% of the 28 days resistance level only 3 days after casting. The following relationship between the two resistances was established for lightweight concrete.

$$R_{2„}= 13+1,1\ R_7 \quad \text{(I)}$$

When it is compared to the one generally applied to conventional concrete, one may note that lightweight concrete hardening is initially much faster than that of conventional concrete as seen from the Equation 2.

$$R_{2S}=40+1,IR_7 \quad (2)$$

5 PUMICE LIGHTWEIGHT CONCRETE - EXPERIMENTAL RESEARCH

A comprehensive experimental research work was carried out to determine the engineering properties of the Turkish pumice lightweight concretes. The tests were performed in the Pumice Research Centre Laboratory of Süleyman Demirel University, Turkey. Different cement dosages were used in each batch. The pumice lightweight concrete mixtures were cast with the cement dosages of 250 and 300 kg/m\

Pumice used in this experimental research, belongs to Kayseri Region, Centre Anatolian of Turkey. It is a crumbly pyroclastic rock characterised by its dark grey colouring. It is rich in highly vesicles volcanic glass which gives it high porosity and low density. It is mostly siliceous and rich in dissolved volatile constituents, especially for water vapour. The most important constituents of this pumice are silica (70 %) and alumina (14%). Also found are iron oxide as 2,5%, calcium oxide as 1%, potassium oxide and sodium oxide as 9%, magnesia, titanium dioxide and manganese oxide in lower levels. Loss at ignition varies from 2% to 3% according to the pumice structure. It has a low thermal conductivity coefficient. Therefore, it is a very good heat insulation material in construction industry.

The same tests are included in the standard for masonry units. However, the limits are not the same in both cases as. for example, in the grading requirements. Here, as a brief explanation, the research findings of the strength characteristics and the elastic properties of the pumice lightweight concrete mixtures prepared were given in the following paragraphs.

Pumice concrete samples were prepared as 10x10x10 cm cube samples. The cube samples were used in testing the mixture strengths and the water/solid ratio was determined as 0.10-0.35 for granulomere mixtures of the cubic samples. To determine the strength of cubic samples, 7, 14 and 28 curing day, cube strength experiments were carried out. Granulometric compositions used in lightweight concrete mixtures are as follows: 16 mm- 8 mm *(Coarse aggregate),* 8 mm - 4 mm *(Metlinm aggregate),* 4 mm - 0 mm *(Fine aggregate).*

The standard lightweight samples were tested after 7 and 28 days curing time to determine the effects of heavy coarse and fine gravel quantities on the reference concrete (no additional admixture-only pumice aggregates) strength). The research findings are plotted in Figure 1 to Figure 10.

In order to improve the mechanical resistance characteristics of pumice concrete, gravel was used instead of fine pumice in several test mixes. In lightweight concrete, unlike in ordinary concrete, the cement mortar (cement + sand + water) has a greater compression resistance than the grain resistance. Consequently, stresses in the gravels arc transferred by the mortar matrix.

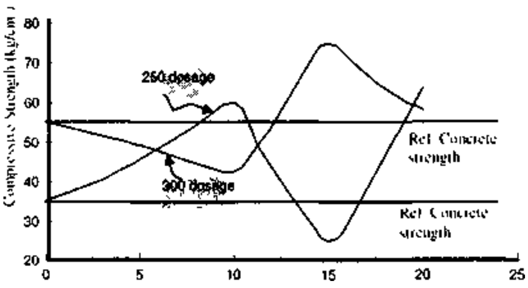

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Figure I Effect of coarse gravel quantity on strength

It can be clearly concluded from the Figure 1 that, when the strength of the concrete samples after 28 days curing time is compared with the reference concrete samples, lower cement content will be more efficient for these types of concretes. In this approach, the optimum gravel usage ratio was defined approximately as 13%. Due to the fact that, the mechanical characteristics of the pumice aggregates are considerably lower than that of dense aggregates, the excessive quantities of gravel in the matrix structure may cause shear forces on the pumice aggregates.

It can be seen from the Figure 2 that, lower cement usage with fine gravel will be more efficient for compression resistance of the concrete after 28 days curing time. When the fine gravel is gradually increased in the reference concrete mixture, higher strength values can be acquired thanks to higher adhesive forces and so more compact structure occuring with pumice aggregates. However, the total percentage of the fine gravel must be optimised to prevent decrease in strength and increase in dry unit volume weights. According to the research findings, it was observed that the most suitable fine gravel content in the matrix structure will be approximately 16%.

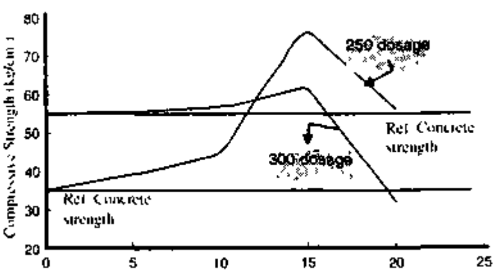

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Figure 2. Effect of fine gravel quantity on strength

In addition to coarse and fine aggregates, the pyrophyllilc was used as 5% volume of cement dosage for reducing the water in the mixture and Re-acquiring the adhesive characteristics to the matrix structure. As can be seen from the Figure 3 that, the pyrophyllilc admixture has a positive affect on the strength characteristics of the samples with respect to occuring stronger bonds between the aggregates and matrix structure. When Figure 3 is investigated in detail, this activity is specially obtained for lower cement dosages. For this reason, in order to obtain high strength matrix structure, so increase the strength of pumice aggregate concrete, a certain quantities of coarse gravel, fine gravel and pyrophyllite admixture must be optimised in the mixture.

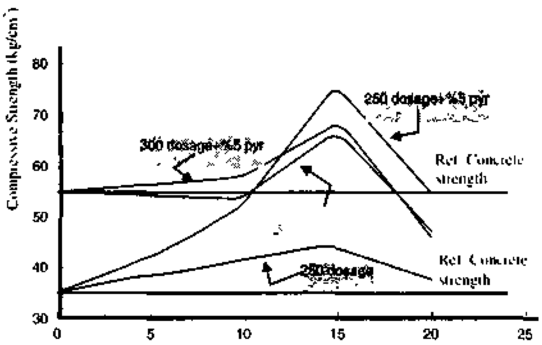

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Figure 'S. Effect of pyrophylhte quantity on siiength

The efficiency and variation percentage ot additional admixtures on the strength of concrete was examined for the matrix structure types mentioned above. From this point of view, the strength changes in the new matrix composition was calculated by percentage in comparison to reference concrete and the acquired results were given in the Figure 4 to Figure 6.

These figures show that the increase in strength of matrix structure is higher for lower cement levels. In addition, it was observed that the reference.

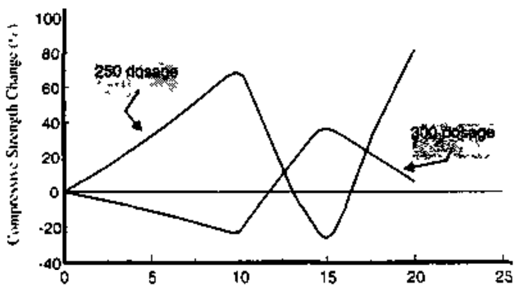

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Figure 4. Increasing ratio of strength lor coarse gravel

concrete strength increased approximately with 120 % by the most efficient matrix structure which is composed of *5%* fine gravel, *5%* coarse gravel and *5%* pyrophyllite by volume of cement dosage

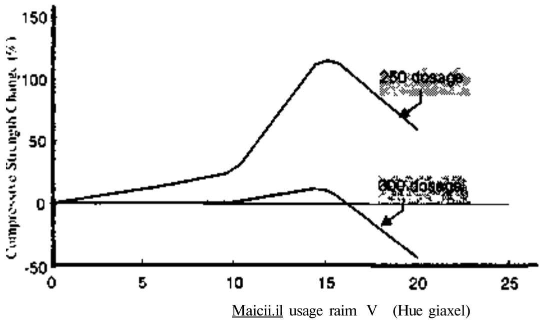

Figure 5. Incıeasıng ratio of strength for tine gravel

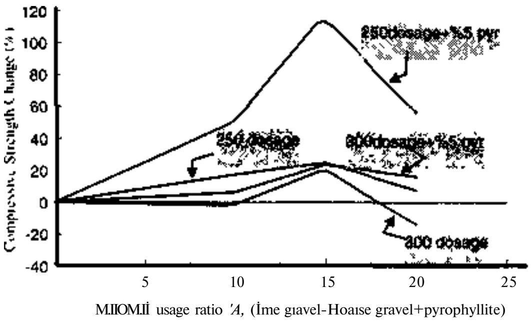

Figure 6 Increasing ratio of strength for pyrophyllite

Another important parameter of the matrix structure which is used for lightweight concrete is the dry unit volume weights of the batches. As known, lower dry unit volume weights and higher strength of matrix structure is generally desired for the obtain high performance lightweight concrete. The analysis findings of the dry unit volume weights were given comparatively in Figure 7 to Figure 10 tor different mixture proportions. From these relationships between the strength and dry unit volume weight, it can be assumed that the increase in cement dosage is more effective on the dry unit volume weights in comparison to different admixtures. However, when the cement dosage is decreased to certain levels, there will be a rational relationship between the dry unit volume weight and the strength of matrix structure. This relation was analysed statistically and the exponential trend was obtained. In other words, the higher dry unit volume weights will cause the higher strength of matrix structure. It can be assumed that from these investigations, the average dry unit volume weights of the matrix structures having different admixtures must be varied between 830-850 kg/m[1] to increase the reference concrete.

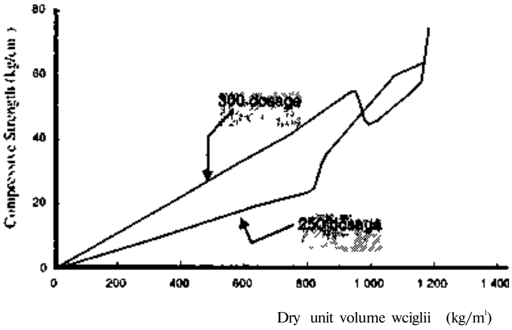

Figure 7 Effect of dry unit volume weight on strength (coarse gravel)

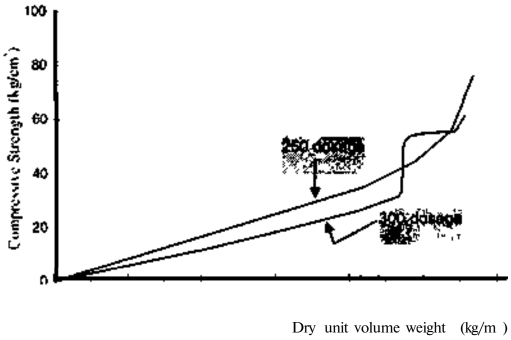

Figure 8. Effect of dry unit volume weight on strength (fine gravel)

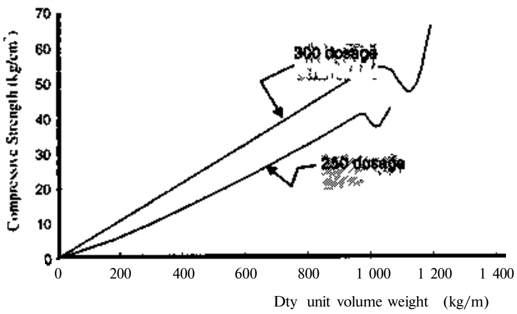

Figure 9 Elfecl of dry unit volume weight on stiength (coarse gravel+fine gravel)

In this research, the general view ot different admixture types used in pumice aggregate concretes was discussed based on the research activity carried out. The eeneral observation is derived as the strength of pumice aggregate concretes could increase with the different additives. However, the care must be taken on which type of additive material should specially be used to increase the concrete strength. This practise could follow by making a series of experimental lest works.

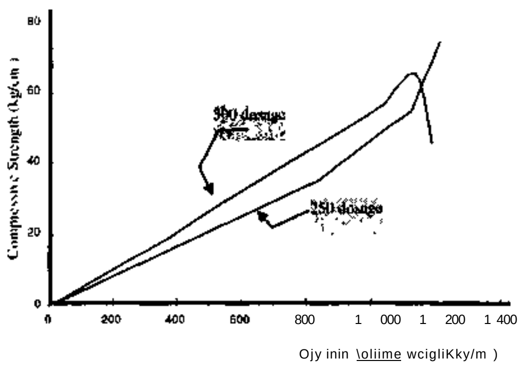

Figure I0. Effect of dry unit volume weight on strength (coarse gravel+fme gravel+pyrophyllite)

5 RESULTS

This paper presents a review on the role of different admixtures in concrete. Various factors such as water /cement ratio, curing conditions and different admixtures have a considerable influence on the concrete strength.

In order to reduce the density for load bearing structural members and to improve the strength properties, a new binder matrix has been investigated. The binder matrix is composed of cement, variable amounts of heavy fine and coarse gravel with pyrophyllite. The use of pumice as lightweight aggregate in combination with crushed gravel and pyrophyllite was found to be advantageous.

In recent years, there has been considerable interest in improving the properties of concrete products by incorporating potentially beneficial materials such as fly ash and pyrophyllite. These materials generally affect the physical and mechanical properties of fresh and hardened concrete.

In addition, it can be clearly concluded that the pumice granulometry used in the mixture combination has a considerable effect on the strength from this approach. Here, the maximum stress value for each block sample of separate mixtures is different from each other and it was also observed that the increasing of line aggregates in the mixture generally affects the maximum strength and strain values. Although the increase in tine aggregates obtains high strength, high quantities of line aggregates are not desired because of causing the high density.

REFERENCES

Bombard H. 198(1. *Lightweight t out rete .strut tura, potentialities, limits ami realities.* The Conciete Society. The Construction Press. Lancester. London. New Yoik, UK.

Bürge A.. 1983. *High Strength Lightweight Cmurele with Condensed Silica Fume. First International Confèrent e On The Use Ol Fir Ash. Silita Fume. Slag tuitl other Mineral Bv-I'rotlut Is in Concrete.* Montebello-Canada

Failla A.. Mancuso P. and Miragha N.. 1997. *Experimental - Theoretital Study on Pumice Aggregate Lightweight Ctmt rete* Technical Report. Italy.

Holm T.A. 1980. Physical properties ot high strength lightweight aggregate concretes. *The Concrete Sot lety. The Construction Press.* Lancester. London. New York, UK.

Kornev N.A.. Kramar V.G. and Kudryavlsev A.A.. 1980. Design peculiarities of-prestressed supporting constructions from concretes on porous aggregates. *The Com rete Society, The Constitution Press.* Lancester. London, New York. UK.

Newman J.B. and Bremner T W.. 1980. The testing of structural lightweight concrete *The Com rete Society, The Constitution Press.* Lancester. London. New York. UK.