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# THE EFFECT OF HIGH TEMPERATURE ON CONCRETE CONTAINING PERLITE POWDER

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## Abstract

This paper reports an experimental study and statistical analysis results carried out to determine high temperature effect on concrete containing perlite powder (PP) as a sustainable admixture material. For this aim, five different concrete samples were produced with PP percentages of 0%, 5%, 10%, 15% and 20% as a replacement of the cement in weight basis. Concrete specimens were heated up to temperatures of 400, 600 and 900°C, then compressive strength and ultrasonic pulse velocity test were performed to identify high temperature effect comparing to the test results obtaining from standard laboratory conditions. Moreover, to determine contribution of PP to the concrete performance, concrete strength and ultrasonic pulse velocity tests were implemented on concrete specimens at the ages of 3, 7, 28 and 90-days. This paper adopts Taguchi approach with an $L_{25}$ orthogonal array to reduce the numbers of experiment. In this study, two control factors (Percentage of PP and Temperature) were used for statistical analysis. It was identified whether or not these parameters had an importance on compressive strength and ultrasonic pulse velocity using analysis of variance (ANOVA) method.

**Key words:** Temperature effect, Perlite powder, ANOVA

# PERLİT TOZU İÇEREN BETON ÜZERİNE YÜKSEK SICAKLIĞIN ETKİSİ

## Özet

Bu makale sürdürülebilir bir katkı malzemesi olarak perlit tozu içeren beton üzerine yüksek sıcaklık etkisini belirlemek için yürütülen deneysel çalışma ve istatistiksel analiz sonuçlarını rapor eder. Bu amaçla, çimento ile ağırlıkça %0, %5, %10, %15 ve %20 oranlarında perlit tozu ile beş farklı beton numunesi üretildi. Beton numuneler 400, 600 ve 900°C' de ısıya tabi tutuldu, daha sonra basınç dayanımı ve ultrasonik ses geçirgenlik deneyleri uygulanarak elde edilen sonuçlar, yüksek sıcaklık etkisini belirleyebilmek için laboratuar ortamından elde edilen sonuçlarla karşılaştırıldı. Bununla birlikte, perlit tozunun beton performansına katkısını belirleyebilmek için beton numuneler üstünde 3, 7, 28 ve 90 günlük yaşlarda basınç dayanımı ve ultrasonik ses geçirgenlik deneyleri uygulandı. Bu makalede deney sayısını düşürmek için Taguchi yaklaşımı ile bir $L_{25}$ ortogonal dizi seçilmiştir. Bu çalışmada istatistiksel analiz için iki kontrol faktörü (Perlit tozu oranı ve Sıcaklık) seçilmiştir. Bu parametrelerin basınç dayanımı ve ultrasonik ses geçirgenlik içi öneme sahip olup-olmadığı belirlenmiştir.

**Anahtar Kelimeler:** Sıcaklık etkisi, Perlit tozu, ANOVA.

## 1. Introduction

Perlite has an important place between the reserved materials in the world, yet considerable importance and interest have not given on it. Erdem et al. (2007) pointed out that there were

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~6700 million tons of perlite reserves in the world and the most portion of it took place in Turkey. Topçu and Işıkdağ (2007) also referred that 70% of world perlite deposits were existing in Turkey. Bektas et al. (2005) and again Topçu and Işıkdağ (2007) indicated that approximately 65% of today's perlite production has been used by the construction industry. In the literature at present time, there are limited researches about perlite material specifically natural perlite powder. Most perlite researches are about expanded perlite such as lightweight concrete technology and heat insulation technology. Demirboğa et al. (2001) investigated the effect of expanded perlite and mineral admixtures on the compressive strength of low-density concretes. They used partially expanded perlite together with pumice as aggregates in the concrete mixes and declared that increasing expanded perlite ratio in the designed mixes improved compressive strength of low-density concretes. Demirboğa and Gül (2003) made another research on thermal conductivity of lightweight concrete produced with partially expanded perlite. It is pointed out that expanded perlite usage cause a decline at thermal conductivity coefficient of designed concretes. Yilmazer and Ozdeniz (2005) studied the acoustical behaviour of the plates produced with expanded perlite usage and reported that moisture resistance of the plates made of expanded perlite, could be improved by adding special mixing materials. Türkmen and Kantarcı (2007) carried out an investigation on some physical and mechanical properties of self compacting concrete containing mixture of expanded perlite aggregate and natural aggregates at different curing regimes.

Definition of perlite material and its some specific properties, physical or chemical characterisation, can be drawn below according to literature:

Perlite is a hydrated volcanic glassy rock containing approximately 70–75% $SiO_2$ and 12–18% $Al_2O_3$. It has a pearly, vitreous luster characterized by concentric onionskin fractures. Its relatively high water content (2%-5%) makes it distinctive from other hydrous volcanic glasses, such as obsidian, hydrated volcanic ash etc (Bektas et al.,2005; Erdem et al., 2007). This chemically water content of perlite boils doe to rapid heating at the temperatures in the range of 800-1150°C and then constitutes a new form of perlite which is expanded, soft and light bubbles. During the formation of these bubbles, crude perlite expand up to 10–25 times of its original volume (Bektas et al.,2005; Erdem et al., 2007; Topçu, İ. B. and Işıkdağ, B., 2008). This cellular material having low bulk-density is called "expanded perlite" and used in various constructional, horticultural and industrial applications. Owing to perlite's vitreous structure and high $SiO_2$ and $Al_2O_3$ contents, it can be said that perlite is a pozzolanic material (Erdem et al., 2007). Yu et al. (2003) also declared that perlite had a high pozzolanic effect and was an active mineral admixture for concrete. The majority of researchers have mostly focused on the lightness and insulation properties of expanded perlite. Even though its pozzolanic effects have been mentioned in some limited numbers of technical papers, no investigation has so far been made on the use of natural perlite powder in concrete technology as a pozzolanic admixture material. Hence, this paper present an experimental study and statistical analysis result conducted out to determine the contribution PP as a pozzolanic admixture to the characteristic performance of concrete such as compressive strength and ultrasonic pulse velocity values at different ages and under different temperatures. Through this way, it has been aimed reducing the cement consumption, indirectly concrete cost and $CO_2$ emission as well thanks to easily availability of PP

## 2. Experimental Study

### 2.1. Materials, Methods and Testing

In this study, CEM I 42.5 Class N, normal Portland cement 42.5, which was produced in Elazig in Turkey was used. PP was obtained from Erzincan-Mollatepe in Turkey. The chemical composition and some physical properties of Portland cement and PP were given in Table 1. The fine and coarse aggregate were natural aggregates obtained from Murat River in Turkey. The relative density, water absorption and percent loss (after 500 revolutions in Los Angeles testing machine) of coarse aggregate were 2700 kg/m$^3$, 2% and 16.4%, respectively. The Nominal maximum size of coarse aggregate used was 16mm.

The concrete constituents were mixed in a revolving pan type mixer. A control concrete mixture made at 55% fine/45% coarse aggregates rates containing only Portland cement at the dosage of 400 kg/m$^3$ (%0P), and concrete mixture containing 5%, 10%, 15% and 20% PP as a replacement of the cement by mass were prepared. After mixing, fresh concrete mixtures were filled in cubic moulds, 100x100x100 mm, in three layers. Later, all the test specimens were stored at temperature of 22±3ºC (about 23ºC) in the laboratory. On the day following casting, the specimens were de-moulded and placed in 22°C water for periods of 3, 7, 28 and 90-days. At the end of the each curing period, a total of 3 specimens were tested for compressive strength and ultrasonic pulse velocity. To identify influence of high temperature on concrete produced with and without PP, concrete samples exposure the temperatures of 400, 600 and 900°C at the end of the 90th day. Both before and after heating tests, compressive strength and ultrasonic pulse velocity tests were performed on all concrete samples to compare strength and p- wave velocity losses.

Table 1. Chemical composition and physical properties of cement and PP

| | **PC 42,5** | **PP** |
|---|---|---|
| **$SiO_2$** | 21.12 | 69.64 |
| **$Al_2O_3$** | 5.62 | 12.53 |
| **$Fe_2O_3$** | 3.24 | 1.67 |
| **CaO** | 62.94 | 3.28 |
| **MgO** | 2.73 | 0.73 |
| **$SO_3$** | 1.79 | - |
| **LoI** | 1.78 | 4.28 |
| **Blaine, cm$^2$/g** | 3382 | - |
| **Spes.Grav, g/cm$^3$** | 3.07 | 2.21 |
| **$f_{ce}$, N/mm$^2$** | 51.7 | - |

### 2.2. Taguchi Methods and Statistical Analysis

After the Second World War, Dr Taguchi developed a new method to optimize the process of engineering experimentation. That technique is known as the Taguchi Method (Roy, 1990). In Taguchi method, a loss function is used to calculate the deviation between the experimental value and desired value. That loss function is further transformed into a signal-noise (S/N) ratio (Tosun and Ozler, 2004). There are different types of S/N ratios available, depending on the type of the characteristics. The most used characteristics types are “Larger is Better (LB), Nominal is the Best (NB) and Smaller is Better (SB)”. As a concrete characteristic, the larger compressive strength and p-wave velocity have given the better performance. In this study, therefore, larger is better performance characteristic was used. The definition of the loss function (L) for LB is:

$$L_{ij} = \frac{1}{n}\sum_{k=1}^{n}\frac{1}{y_{ijk}^{2}} \tag{1}$$

and the formulation of S/N ratio is given below.

$$S/N_{ij}=-10\log(L_{ij}) \tag{2}$$

Where $L_{ij}$ is the loss function of performance characteristic *i* in the experiment *j* and *n* is the number of tests. As for the *y*, it expresses the experimental value of the performance characteristic *i* in the experiment *j* at the test *k*. Control parameters and their levels used to calculate the S/N ratios are given Table 2.

Table 2. Control parameters and levels

| **Cont. Factors\levels** | **L1** | **L2** | **L3** | **L4** | **L5** |
|---|---|---|---|---|---|
| **Temperature, °C** | 20 | 400 | 600 | 900 | - |
| **Perlite, %** | 0% | 5% | 10% | 15% | 20% |

## 3. Result and Discussion

Figure 1 presents the compressive strength results of concrete specimens at the ages of 3, 7, 28 and 90 days. It can be seen that the highest compressive strength values were obtained from the 0%P and 5%P specimens followed by the 10%P, 15%P and 20%P specimens at the end of the 90 days curing period. 0%P and 5%P concrete specimens gave the similar compressive strength results at all ages. 10%P, 15%P and 20%P specimens gave the lesser strength values of 9%, 14.8% and 24.8 comparing to 0%P specimen at 90 curing days, respectively. On the other hand, strength improvements of all concrete specimens from 28 days (standard age) to 90 days are 4.4% (0%P), 5.4% (5%P), 19% (10%P), 8.8% (15%P) and 8.4% (20%P), respectively. Moreover, similarly strength improvements from 7 days (early age) to 90 days are 37.7% (0%P), 32.7% (5%P), 34.4% (10%P), 31.7% (15%P) and 38.4% (20%P), sequentially. From the Figure 1, it is clearly seen that increasing partially incorporating rates of PP to the concretes caused the strength decline. Hence, in the aspect of strength improvement mentioned above, incorporation of PP as a pozzolanic admixture to the concrete results the strength development. Of course, another issue is cement replacement in weight basis. 10%P usage instead of cement led to 19% (28-90 days) and 34.4 (7-90 days) compressive strength developments, respectively. 15%P replacement with cement resulted 8.8% (28-90 days) and 31.7% (7-90 days) compressive strength developments, respectively. Similarly, 20% decreasing of cement ratio and adding 20%P be half of cement provided 8.4% (28-90 days) and 38.4% (7-90 days) compressive strength improvements, sequentially. Although, this result shows there is just a little surpass or improvement levels comparing to 0%P series, anyway, it proves that there is a positive effect thanks to pozzolanic effect of PP. As seen in Figure 2, very similar results were obtained from the ultrasonic pulse velocity tests. 0%P and 5%P gave the highest result than the others at the end of the 90 days curing period. In all ages, the lowest ultrasonic pulse velocity values were obtained from the 20%P specimens. Hence, all other specimens with and without PP gave very close ultra sonic pulse velocity values each other at all curing ages.

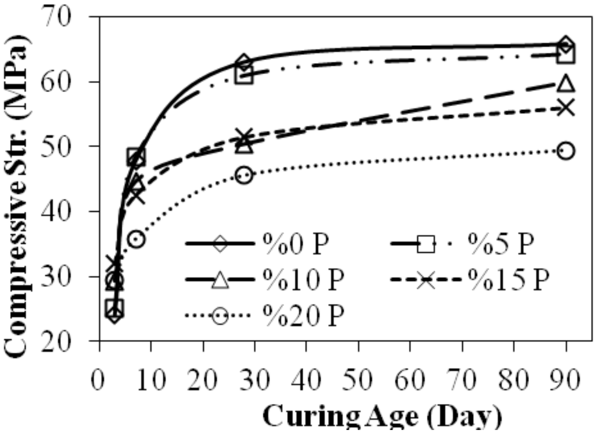

Figure 1. Compressive strength results of concrete samples

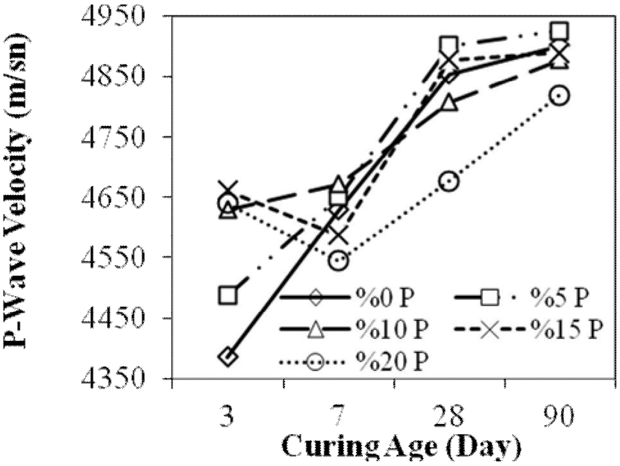

Figure 2. Ultrasonic pulse velocity values of concrete samples

Table 3 present S/N ratios of control factor levels belonging compressive strength and ultrasonic pulse velocity values. Statistical analysis results are also presented in Table 4 and Figure 3-4. It can be seen from the tables relating to ANOVA and F-test that control factors, temperature and PP%, have high F values and so low P values. That situation indicates that these control factors have importance and effect on the performance characteristics of concrete. Between the control factors, the temperature has higher importance and effect than PP% both for compressive strength and ultrasonic pulse velocity values. This statistical result has confirmed the experimental test result. UPV as a performance characteristic shows similarity with compressive strength Figure 3-4 also verify experimental test results. As a general result, it can be said that the best results are obtained from the 20°C temperature and containing 5%PP for compressive strength while the worst results are achieved from the 900°C temperature and containing 20%PP for compressive strength.

Table 3. S/N ratios of factor levels

| Compressive Strength | | | | | |
|---|---|---|---|---|---|
| **C. Factors \ Levels** | **L1** | **L2** | **L3** | **L4** | **L5** |
| **Temperature, °C** | 39,02 | 37,43 | 36,50 | 18,59 | - |
| **Perlite, %** | 33,51 | 34,00 | 33,05 | 32,22 | 31,63 |
| **Ultrasonic Pulse velocity** | | | | | |
| **Temperature, °C** | 40,00 | 38,33 | 35,57 | 29,54 | - |
| **Perlite, %** | 36,22 | 35,96 | 35,48 | 35,34 | 36,30 |

Table 4. ANOVA Results

| **Control Factors** | **Degrees of Freedom** | **Sum of Square** | **Variance** | **F** | **P** |
|---|---|---|---|---|---|
| **Compressive Strength** | | | | | |
| **Temperature(°C)** | 3 | 1378,34 | 459,447 | 753,58 | 0,000 |
| **Perlite (%)** | 4 | 14,78 | 3,694 | 6,06 | 0,007 |
| **Error** | 12 | 7,32 | 0,610 | | |
| **Ultrasonic Pulse velocity** | | | | | |
| **Temperature(°C)** | 3 | 316,690 | 105,563 | 588,62 | 0,000 |
| **Perlite (%)** | 4 | 3,004 | 0,751 | 4,19 | 0,024 |
| **Error** | 12 | 2,152 | 0,179 | | |

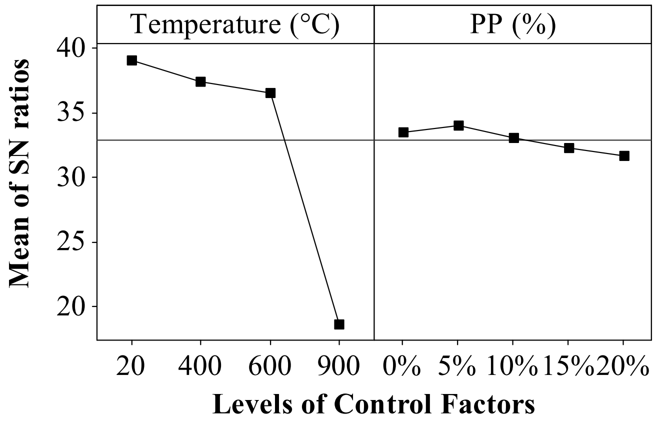

Figure 3. Main effects plot of S/N ratios for compressive strength

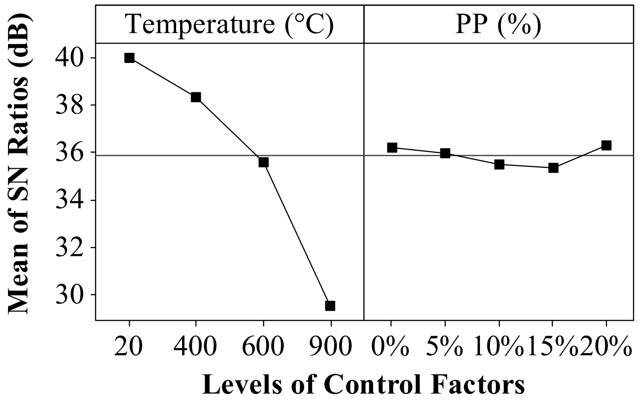

Figure 4. Main effects plot of S/N ratios for P-wave velocity values

## 4. Conclusions

0%P and 5%P concrete specimens gave the similar compressive strength and ultrasonic pulse velocity results at all ages. The highest compressive strength and ultrasonic pulse velocity values were obtained from the 0%P and 5%P specimens followed by the 10%P, 15%P and 20%P specimens at the end of the 90 days curing period. The incorporation of PP provided the better strength improvements on the concrete specimens both from 28 days to 90 days and from 7 days to 90 days although they gave lower strength and ultrasonic pulse velocity values. Statistical analysis result verified the experimental test result. PP usage reduced the cement consumption, indirectly concrete cost and $CO_2$ emission as well.

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