# Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 8 (7): 1340-1345, 2008
ISSN 1812-5654


# Quantitative Analysis of Pumice Effect on Some Physical and Mechanical Properties of Clay Bricks

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**Abstract:** This study was conducted to evaluate the effect of pumice on some physical and mechanical properties of clay bricks fired under varying firing temperatures. Brick samples comprising varying amounts of pumice were prepared, mixing the clay material pumice in gradually increasing ratios. Increasing rate of pumice gradually decreased bending strength, compressing strength, density, firing shrinkage and heat conductivity; and gradually increased the water adsorption of the brick produces under reach of 800, 900 and 1000°C. It was concluded that pumice can be safely used to improve mechanical and physical properties of the final material, provided that the ration of pumice to clay should not be exceed unity.

**Key words:** Clay brick, pumice, mechanical properties, heat conductivity

## INTRODUCTION

In the transition process from traditional methods to industrialized building technologies, use of light construction materials which contribute to energy saving has increasingly been gained importance. Naturally, the use of Light Weight Concrete (LWC) has been confined to large structures and, more in particular, to structures where a high dead load to live load ratio occurs. Furthermore, the reduced weight may make LWC preferable for structures in seismic zones, because of the reduced dynamic actions; it makes it easier to move the elements to be connected (Cavaleri *et al*., 2005).

One of the most conventional ways to improve insulation capacity of a brick is to improve porosity. Adding lightweight aggregates to ceramic body can form pores. Most frequently used pore formers in clay brick manufacturing can be classified into two groups: Organic and inorganic pore generators. Sawdust, styropor, paper sludge, coal and coke are organic; and perlite, diatomite, lime flour, pumice and vermiculite are inorganic (mineral) type pore formers (Demir *et al*., 2005). Such aggregates are available in various parts of the world and can be used in producing brick in a wide range of unit weights and suitable strength values for different applications (Demirboga *et al*., 2001). In addition to improving heat and acoustic insulation, lightness of material produced using lightweight materials in bricks provides great advantage in certain applications such as bridge decks, parking garages, long span viaducts and so on (Balaguru and Foden, 1996; Duzgun *et al*., 2005).

Pumice, an extremely light, porous raw material of volcanic origin, can be found in many parts of the world, including various developing countries with areas of past or present volcanic activities (Grasser and Minke, 1990). Pumice is used in many applications such as in chemical, dental, cosmetic, abrasives, cement, concrete, ceramic and glass industries as it is an inexpensive and widespread geological raw material. In addition, pumice is widely used in the construction industry (Poyraz *et al*., 2005). Pumice has been used in cement and as an aggregate in the production of lightweight concrete (LWC) in many countries of the world (Cavaleri *et al*., 2005). LWC masonry units are defined as the ones having a minimum compressive strength of 3.5 MPa without exceeding an air-dry unit weight of 1680 kg $m^{-3}$. In addition to the lightness, LWCs, made up of lightweight aggregates, have other superior properties such as, thermal isolation, freeze-thaw resistance and fire protection but have the disadvantage of having low mechanical properties (Demirboga *et al*., 2001).

That pumice deposits are abundant in Turkey accommodates production of inexpensive lightweight bricks to be used especially in agricultural buildings. The aim of this study was to quantitatively analyze the effect of pumice mixed with clay material in different ratios on bending strength, compressive strength, density, firing shrinkage, water absorption and heat conductivity of bricks produced each 800, 900, 1000°C firing temperatures.

## MATERIALS AND METHODS

**Properties of brick raw material:** Clay material for brick samples was taken from one of brick manufacturing plant in Tokat and grinded pumice (<212 μm) from Van-Erciş

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Table 1a: Some physical and chemical properties of raw material used in the sample preparation (%)

| $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | Burning losses | LL [a] | PL [b] | PI [c] | Sand | Silt | Clay | Texture class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 48.55 | 16.83 | 6.80 | 5.15 | 6.19 | 0.94 | 6.34 | 33.23 | 24.65 | 8.64 | 12.8 | 44 | 43.2 | SiC |

Table 1b: Physical and chemical properties of pumice (%)

| MgO | $Al_2O_3$ | $SiO_2$ | CaO | $Fe_2O_3$ | $SO_3$ | $K_2O$ | $Na_2O$ | $TiO_2$ | Burning losses |
|---|---|---|---|---|---|---|---|---|---|
| 1.01 | 13.20 | 71.35 | 1.84 | 1.54 | 0.04 | 5.00 | 3.40 | 0.25 | 3.37 |

[a]Liquid limit, [b]Plastic limit, [c]Plasticity index

Table 2: Some physical and mechanical properties of bricks produced under different firing temperatures and varying pumice concentrations

| Pumice rate (%) | Firing temperature (°C) | Firing shrinkage (%) | Density (g $cm^{-3}$) | Water absorption (%) | Compressive strength (MPa) | Bending strength (MPa) | Heat conductivity (W $mK^{-1}$) |
|---|---|---|---|---|---|---|---|
| 0 | 800 | 6.7 | 1.62 | 18.40 | 12.45 | 3.73 | 0.62 |
| | 900 | 7.5 | 1.70 | 15.60 | 15.99 | 4.90 | 0.65 |
| | 1000 | 8.0 | 1.73 | 13.09 | 22.56 | 6.67 | 0.77 |
| 10 | 800 | 6.5 | 1.56 | 20.00 | 8.92 | 3.24 | 0.60 |
| | 900 | 7.2 | 1.67 | 18.21 | 13.04 | 4.32 | 0.60 |
| | 1000 | 7.7 | 1.74 | 15.27 | 20.20 | 5.98 | 0.67 |
| 20 | 800 | 6.2 | 1.45 | 20.50 | 8.14 | 2.16 | 0.57 |
| | 900 | 6.7 | 1.52 | 18.50 | 11.87 | 3.24 | 0.60 |
| | 1000 | 7.4 | 1.59 | 15.40 | 19.12 | 4.90 | 0.64 |
| 30 | 800 | 6.1 | 1.38 | 21.30 | 5.79 | 2.06 | 0.54 |
| | 900 | 6.6 | 1.48 | 18.94 | 10.30 | 2.94 | 0.58 |
| | 1000 | 6.8 | 1.52 | 17.00 | 16.77 | 4.90 | 0.61 |
| 40 | 800 | 5.8 | 1.36 | 21.10 | 5.30 | 1.37 | 0.50 |
| | 900 | 6.4 | 1.43 | 19.31 | 8.73 | 2.55 | 0.53 |
| | 1000 | 6.8 | 1.49 | 16.25 | 15.59 | 4.22 | 0.58 |
| 50 | 800 | 5.8 | 1.32 | 23.21 | 4.51 | 1.08 | 0.51 |
| | 900 | 6.2 | 1.39 | 21.72 | 8.83 | 2.45 | 0.54 |
| | 1000 | 6.5 | 1.43 | 17.46 | 15.20 | 4.02 | 0.58 |
| 60 | 800 | 5.6 | 1.28 | 25.66 | 4.31 | 1.27 | 0.41 |
| | 900 | 6.2 | 1.38 | 23.24 | 8.04 | 2.06 | 0.43 |
| | 1000 | 6.5 | 1.41 | 20.21 | 13.83 | 3.14 | 0.46 |
| 70 | 800 | 5.4 | 1.27 | 27.68 | 3.24 | 1.08 | 0.43 |
| | 900 | 6.2 | 1.33 | 25.94 | 7.45 | 2.16 | 0.43 |
| | 1000 | 6.4 | 1.40 | 22.51 | 10.00 | 3.04 | 0.45 |
| 80 | 800 | 5.4 | 1.19 | 23.16 | 2.94 | 1.08 | 0.39 |
| | 900 | 6.1 | 1.28 | 26.18 | 6.96 | 2.56 | 0.40 |
| | 1000 | 6.5 | 1.35 | 28.65 | 9.61 | 3.33 | 0.41 |
| 90 | 800 | 5.3 | 1.16 | 28.92 | 2.94 | 0.49 | 0.33 |
| | 900 | 5.9 | 1.23 | 27.04 | 5.49 | 1.77 | 0.35 |
| | 1000 | 6.3 | 1.27 | 24.18 | 8.34 | 2.88 | 0.37 |

region, Turkey. Major chemical components of soil samples were analyzed with a Rigaku 3270 X-ray fluorescence spectrograph. The mineralogy of samples was determined by X-ray diffraction (Jackson, 1975), using a DMAX IIIC diffractometer. Elements in soil samples were analyzed in Atomscan Sequential Plasma (ICP-AES) machines. Soil texture was analyzed by Bouyocous Hydrometers (Gee and Bouder, 1986) and plastic and liquid limits and plasticity index were determined by the method described by Mitchell (1976). Some physical and chemical properties and elemental composition of raw materials (clay and pumice) used in the sample preparation are presented in Table 1a, b.

**Sample preparation and tests:** To investigate the extent of pumice effect on bricks, different amounts of pumice were added to clay. Ten different bricks were prepared, gradually increasing the pumice amount in the mixture, from on 0 to 90% with the steps of 10% increment.

Sample size was 4×4×16 cm in a form of rectangle prism. An electric cooker, which can reach up to maximum temperature of 1200°C was used (Toydemir, 1978; Anonymous, 1986). Bricks were fired at 800, 900 and 1000°C to investigate the effects of different firing temperatures on pumice added bricks.

As required by Anonymous (1986) and Anonymous (1979) standards for building bricks, the produced bricks were tested for compressive and bending strength, water absorption, density, firing shrinkage and thermal conductivity. Compressive strength test was performed using a 200 t capacity Alfa brand hydraulic press. Heat conductivity factors were obtained with a using KYOTO 500 device by hot wire method.

**Statistical analyses:** Normality test was conducted to test the hypothesis that assumes each property at each firing step and pumice content has a normal distribution. Regression analyses were performed between pumice content and properties evaluated. The results from the regression analyses were evaluated based on mean absolute error and coefficient of determination and then functions adequately describing the relationship between pumice rates and each of subjected properties were determined.

## RESULTS AND DISCUSSION

Properties of ten samples used at each test for all compositions and averages are presented in Table 2. Mineralogical composition of clay material used in this study was a mixture of illite, kaolinite, chlorite, dolomite, hematite and quartz. None of these minerals was dominated in the mixture. Due to the absence of smectite, plastic and liquid limits of the brick raw materials used in this study were low enough to allow bricking. This sort of particle size distribution along with the mineralogy mentioned above provides the material to possess low plasticity (Table 1).

**Bending strength:** The results indicated that increasing the ratio of pumice resulted in the bending resistance to gradually decrease in bricks produced at all temperatures evaluated (Fig. 1). A second degree polynomial regression equation adequately described the relationship between bending strength and pumice content of the bricks. Figure 1 shows that the bending resistance of bricks rapidly decreased with initial addition of pumice until 50% however, above this concentration the decrease in bending resistance was relatively slow. Increasing temperature at the same pumice contents resulted in bricks with greater bending strengths.

**Compressive strength:** All construction materials must resist stress resulting from the load of the building. The

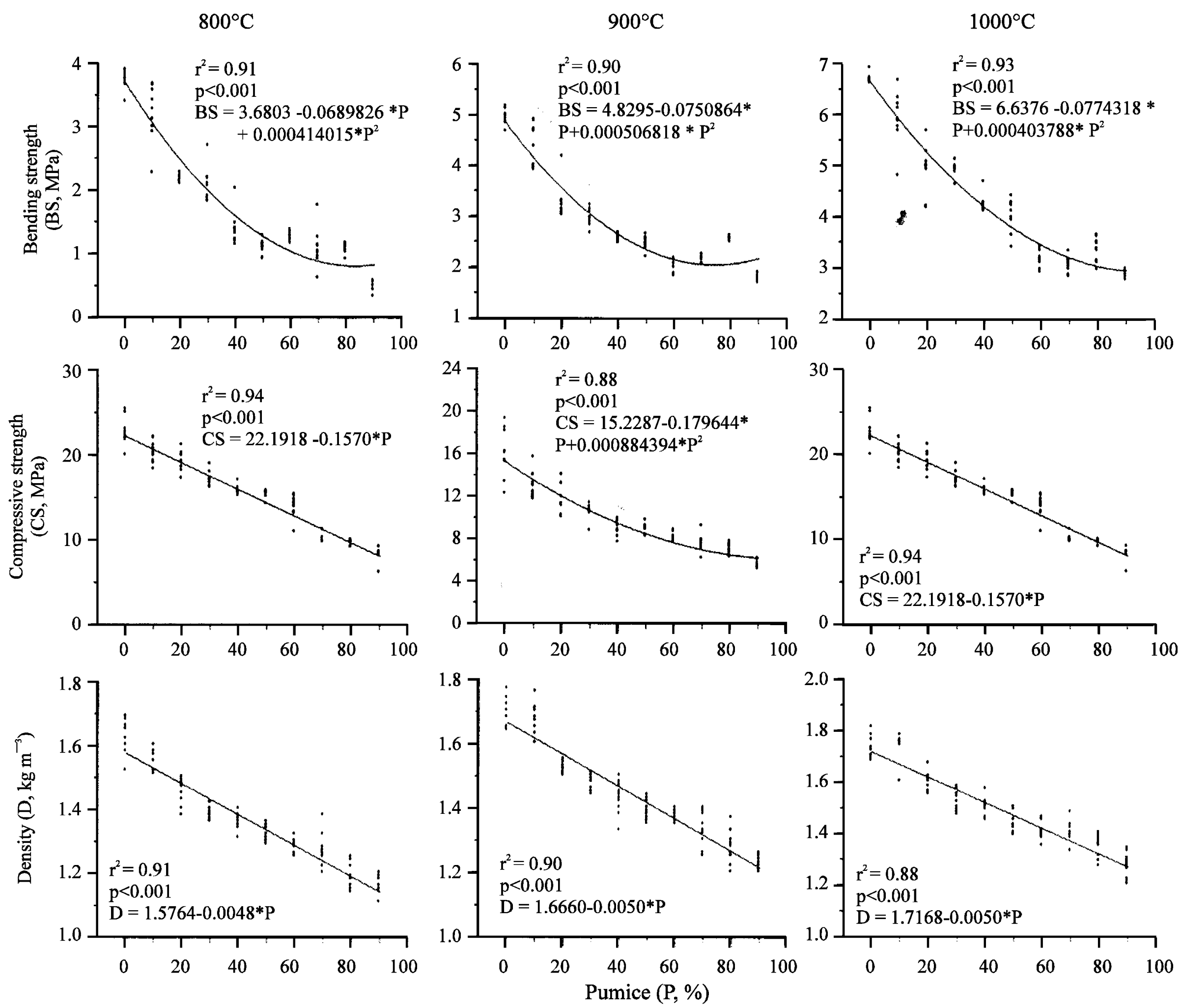


Fig. 1a: Effect of pumice content on some properties of clay bricks produced under different temperatures

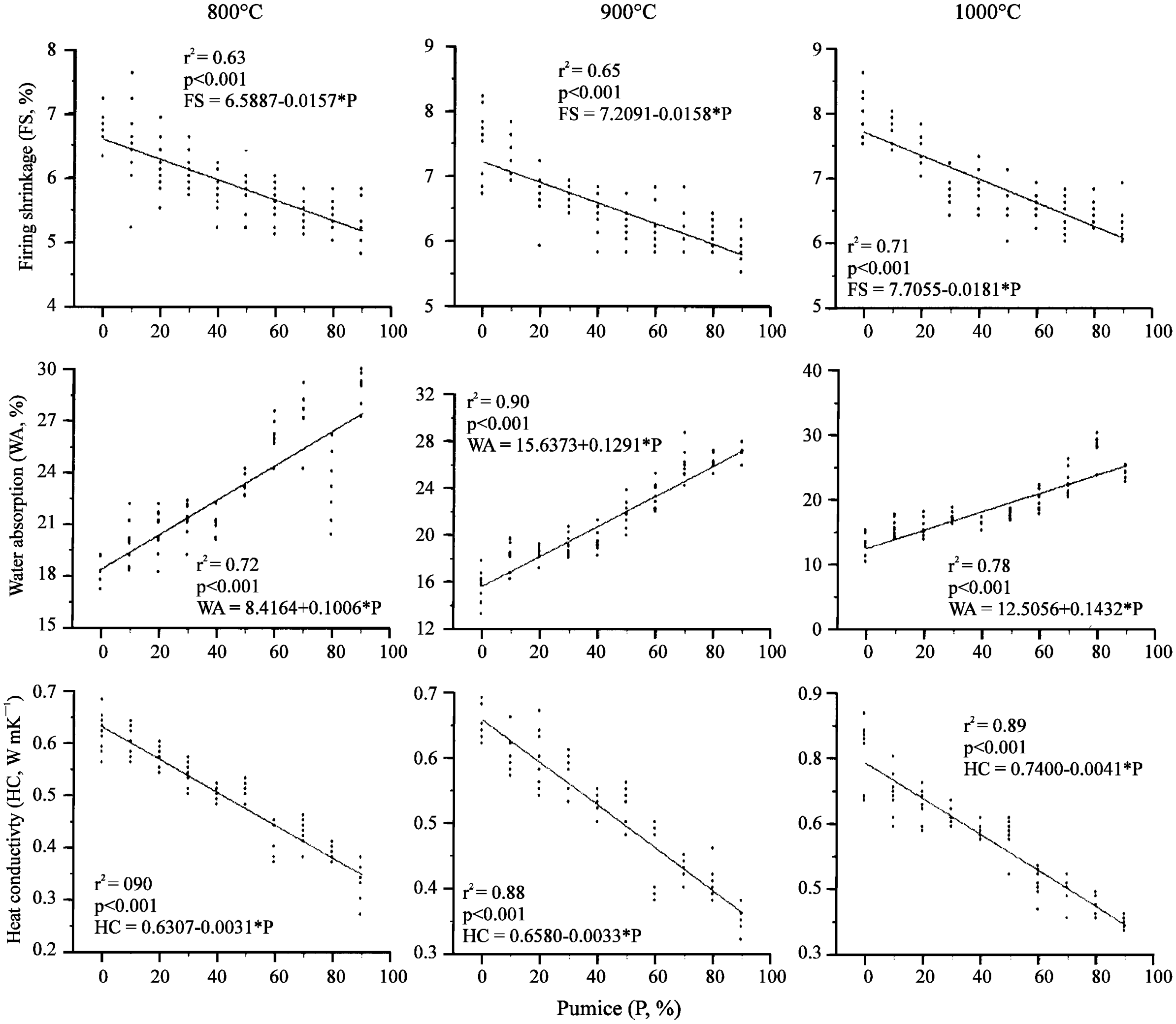


Fig. 1b: Effect of pumice content on some properties of clay bricks produced under different temperatures

strength of material, in general terms, is the ability to resist a force. It equals to stress that the material can resist (Mbumbia *et al*., 2000). The compressive strength of bricks used in carrier walls of one or two flatted buildings in agricultural areas gains importance.

Compressive strength of materials decreased with increasing rate of pumice in the bricks. As compressive strength is largely depending on the firing temperature, the strength of the brick was remarkably improved by firing at high temperature at given pumice/clay ratios. Decreasing trend of compressive strength was similar in bricks fired at 800 and 1000°C, that a linear regression equation adequately explained the relationship between pumice content and compressive strength. However, a second degree polynomial regression equation described the same relationship for bricks fired at 900°C (Fig. 1)

**Density:** Density of a clay brick depends on specific gravity of the raw material used, method of manufacturing and degree of burning (Somayaji, 1995). As density of a brick decreases, its strength and heat conductance also decreases, while its, water absorption increases. In this study, density of pumice added bricks (1.16 g $cm^{-3}$) decreased as compared to bricks without pumice (1.62 g $cm^{-3}$) fired under the same temperature. A linear regression equation successfully described changes in density as a function of pumice rate. Clay particles are irreversibly transformed into solid bodies by silicate bonding (sintering or vitrification) during firing stage of brick preparation. This is a complex and heat sensitive process which is accompanied by shrinkage of clay body. Therefore, density of bricks at a given pumice/clay ratio remarkably increased by firing at higher temperatures.

**Firing shrinkage:** Shrinkage in ceramic products can be explained as water leaving a body, which is used to shape a product. When water between clay particles leaves, particles come closer and shrinkage occurs. Thus firing temperature is a key factor to be controlled to minimize the shrinkage in the firing process. Normally, a good quality of brick exhibits shrinkage below 8% (Weng *et al*., 2002). Firing shrinkage of bricks produced in this study was less then eight percent. Shrinkage of bricks increased with increasing firing temperature, however, addition of pumice decreased the magnitude of shrinkage. A linear regression equation successfully described the changes in firing shrinkage of clay bricks as a function of pumice rate under all temperatures evaluated (Fig. 1).

While pumice prevents formation of splits and cracks by decreasing firing shrinkage, it provides a more rational and economical production by decreasing the firing time. The defects occurring during drying decreases as pumice in the material provides more homogeneous drying.

**Water absorption:** Water absorption is a key factor affecting the durability of bricks. Lesser amount of water infiltrates into brick, more durability of a brick resistance to natural environment are expected. Thus internal structure of brick must be dense enough to avoid water intrusion (Weng *et al*., 2002). The average water absorption of bricks determined by submersion in water for 24 h must be less than 18% (Anonymous, 1979).

In our study, water absorption of bricks decreased with increasing the temperature. However, amount of pumice added increased the water absorption rate, linearly (Fig. 1). Indeed, high water absorption feature is a natural consequence of water absorption characteristic of pumice. Water absorption of clay bricks was lower than 18% up to pumice to clay ratio of unity. However the water absorption exceeded 18% with ratios of pumice to clay greater than unity. Increasing water absorption causes bricks to adhere each other and this weakens the wall strength. Thus, resistance of bricks against frost also increases with decreasing water absorption.

**Heat conductivity:** Heat conduction of a material varies depending on the amount and size of pores in the material and its unit weight. Pumice is an extremely light and porous material, therefore, pumice-added clay bricks seem to be good insulators. Since pumice addition decreases the density of bricks, porosity should increase as well. Increasing the firing temperature caused to obtain less porous material and increased the heat conductivity of bricks. However, pumice addition resulted in a linear decrease in heat conductivity of clay bricks (Fig. 1). Heat conductivity of bricks decreased to 0.33 W $mK^{-1}$, which is close to heat conductivity value of gas concrete and pumice concrete blocks recommended in (Anonymous, 1979).

## CONCLUSIONS

Mixing pumice with clay material significantly altered the compressive strength, firing shrinkage, water absorption and heat conductivity of bricks product at varying firing temperatures. Bricks fired at higher temperatures exhibited higher compressive strength at a given pumice ratio. Increasing rate of pumice added to clay gradually decreased the density of the final products, showing that it is possible to produce cheaper and lighter bricks with pumice addition. Heat conductivity directly affects energy saving. Therefore, due to high thermal insulation features of light bricks, considerable energy saving is possible. Under the socio-economic conditions of Turkey, energy saving will contribute to the budgets of farmers.

The data obtained for drying shrinkage and bending strength of bricks produced showed that pumice can be used to stabilize drying period of clay bricks. The results further showed that pumice could be effectively used to form porous bricks up to 50% addition levels; further additions results in excessive water absorption of bricks that is not desired. It is possible to produce bricks in various qualities and features, varying the rate of pumice in the mixture of raw material used in brick production.

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