Building panel production incorporated with fly ash

G Yıldırım\(^1\), H Keser\(^1\), N Doğan-Sağlamtimur\(^{1,2}\) and F Çelik\(^3\)

\(^1\)Department of Environmental Engineering, Niğde Ömer Halisdemir University, Turkey
\(^2\)Nanoteknoloji Application and Research Center, Niğde Ömer Halisdemir University, Turkey
\(^3\)Department of Civil Engineering, Niğde Ömer Halisdemir University, Turkey

E-mail: neslihandogansaglamtimur@gmail.com, nds@ohu.edu.tr

Abstract. With the increase in industrialization, the amount of fly ash (FA), which is one of the industrial solid wastes causing environmental and human health problems, is increasing day by day. Waste valorization and reuse methods need to be developed for this waste ash. The construction industry is the main sector where it is used. In this study, it is aimed to evaluate the usability of industrial FA in the production of economical and useful building panels and to determine their physical-mechanical properties. FA supplied from İsken Şugözü Thermal Power Plant (ISTPP), ordinary Portland cement (OPC) supplied from ÇIMSA Cement Industry and Trade Inc., molding plaster (MP) and lime are the materials of this study. Particle distribution curves were determined by using laser scattering method for FA\(_{ISTPP}\). In this study, compressive and flexural strengths, water absorption, bulk density and porosity as mechanical and physical tests were made in the building panels having the combination of FA\(_{ISTPP}\)+cement FA\(_{ISTPP}\)+MP and FA\(_{ISTPP}\)+lime in contribution ratios of 10, 30, 50, 70 and 90%. The results of the experiments show that the highest compressive strength values in 7 and 28 days found in the building panels having combination of 90% cement+10% FA\(_{ISTPP}\) are 57.30 and 64.20 MPa, respectively. It was determined that the value-added building panels could be produced from FA\(_{ISTPP}\), an industrial solid waste, in the appropriate proportions of cement contribution.

1. Introduction
Fly ash (FA) that is generated during the combustion of coal for energy production is an industrial by-product recognized as an environmental pollutant. Because of the environmental problems caused by the FA, considerable research has been undertaken on the subject worldwide. It has been found that FA is a promising adsorbent for the removal of various pollutants. The adsorption capacity of FA may be increased after chemical and physical activation. It was also found that FA has good potential for usage in the construction industry [1-5]. Finding means of utilizing waste products is a very important field of research at the moment.

Cement is made by heating a mixture of limestone and clay, or other materials of similar bulk composition and sufficient reactivity, ultimately to temperature of about 1450 °C. Particular fusion occurs, and nodules of clinker are produced. The clinker is mixed with a few percent of calcium sulfate and finely ground, to make the cement [6]. Cement, one of the most important building materials, is a binding agent that sets and hardens to adhere to building units such as stones, bricks, tiles, etc. Cement generally refers to a very fine powdery substance chiefly made up of limestone...
(calcium), sand or clay (silicon), bauxite (aluminum) and iron ore, and may include shells, chalk, marl, shale, clay, blast furnace slag, slate [7-9]. Cement mixed with water causes a chemical reaction (hydration process) and forms a paste that sets and hardens to bind individual structures of building materials. Cement is an integral part of the urban infrastructure. It is used to make concrete as well as mortar, and to secure the infrastructure by binding the building blocks. Concrete is made of cement, water, sand, and gravel mixed in definite proportions, whereas mortar consists of cement, water, and lime aggregate [10, 11]. These are both used to bind rocks, stones, bricks, and other building units, fill or seal any gaps, and to make decorative patterns. Cement, though different from the refined product found nowadays, has been used in many forms since the advent of human civilization. The cement used today has undergone experimentation, testing and significant improvements to meet the needs of the present world, such as developing strong concretes for roads and highways, hydraulic mortars that endure sea water and stucco for wet climates [12-15].

Molding plaster/Gypsum plaster (calcium sulfate hemihydrate) is a material largely employed in civil construction. It is produced by the calcination of the mineral gypsum (calcium sulfate dihydrate) in low temperatures related to other binders. Molding Plaster (MP), commonly referred to as “Plaster of Paris”, is a beta-hemihydrate gypsum product manufactured from high purity natural occurring white gypsum rock. It is commonly used as a good white base material for formulating various interior oriented construction and industrial compounds, for simple 3-D statuary, architectural castings, and temporary templates where strength and hardness are not important [16]. The molding plaster can be considered as a low energy environmental-friendly binder [17]. The calcination temperature for molding plaster production is low, in the range of 125-180°C, it loses water vapor and the carbon dioxide emissions come from the kiln heat [18]. The use of lime in plastering applications dates back to the construction of the Egyptian pyramids about 4000 BC. Plastering methods were refined by the Greeks and Romans. Early plaster systems could contain lime, gypsum, marble dust, fibers and sand in up to three coats. Modern plasters can contain Portland cement or gypsum products. Exterior plasters, often called stucco, normally contain Portland cement because of its low solubility in water. Interior plasters usually contain gypsum [19].

Lime is a truly versatile material widely used in the construction of buildings. It can be utilized in masonry applications as a component of mortar or of the masonry unit. Lime has been used in building construction for thousands of years to create durable mortar and plaster. Lime provides some benefits for mortar and plaster in both the plastic and hardened state. In the plastic state, lime can enhance workability and water retention. In the hardened state, lime products react with carbon dioxide to regenerate calcium carbonate or limestone. This is a slow, gradual process that increases the hardness of the finished surface and allows for the closing of hairline cracks by a process called autogenous healing. Since initial strength is needed in most applications, additives such as gypsum, cement or “pozzolans” are mixed with lime in construction applications. Lime can react with pozzolanic materials in the mortar or plaster to produce a cement-like product. The strength of lime-based mixes can be modified according to the needs of the particular application [20]. Until the advent of CEMI in the 1800's, hydraulic lime was the principal binder for use in construction [21]. Both hydraulic lime and CEM I are synthetic materials manufactured by the thermal decomposition of a source of calcium carbonate (typically limestone) at high temperatures [22].

In this study, the usability of cement, molding plaster (MP) and lime incorporated with FA which is supplied from İsken Sugözü Thermal Power Plant (ISTPP)-Adana, Turkey for the production of building panel was investigated.

2. Material and Methods

2.1. Material

FA supplied from ISTPP (FA_{ISTPP}), CEM I 42,5 R type Portland cement supplied from ÇİMSA Cement Industry and Trade Inc., MP and lime in commercial types are the materials of this study.
No tests were performed to determine the chemical properties of the cement, the data of the manufacturer/supplier was used.

| Elements   | FA_{ISTPP} | Chemical Composition Results (%) | Binders |
|------------|------------|-----------------------------------|---------|
| SiO$_2$    | 62.28      | 3.59                              | Cement  |
| Al$_2$O$_3$| 21.46      | 18.9                              | MP      |
| Fe$_2$O$_3$| 7.01       | 3.36                              | Lime    |
| CaO        | 1.53       | 63.6                              |         |
| MgO        | 2.37       | 1.57                              |         |
| SO$_3$     | 0.07       | 2.65                              |         |
| K$_2$O     | 3.81       | 0.40                              |         |
| Na$_2$O    | 0.26       | 0.77                              |         |
| Others     | 1.21       | 1.57                              |         |
| H$_2$O     | -          | -                                 |         |
| Loss on ignition (LOI) | 1.78 | 3.59                              |         |

### Table 1. Chemical composition of FA_{ISTPP}, cement, MP and lime.

2.2. Method

In the study, preliminary experiments were carried out according to the chemical composition of the FA_{ISTPP} (Table 1). Sieve analysis (TS EN 13279-1 standard, Figure 1), combustible material (Table 2) and tight bulk density tests (Table 3) were performed for the FA_{ISTPP}. Then, the experiments were done to produce building panel specimens (Figure 2) incorporated with FA_{ISTPP}. Sample sets (FA_{ISTPP}+cement, FA_{ISTPP}+MP, FA_{ISTPP}+lime) were subjected to physical and mechanical tests in the second stage. These tests are (i) flexural strength (FS), (ii) compressive strength (CS), (iii) bulk density (BD), (iv) porosity and (v) water absorption (WA).

![Figure 1. Sieve analysis of FA_{ISTPP}, MP and lime.](image-url)
Table 2. Combustible materials of the FAISTPP, MP and lime.

|       | Temperature (°C) | Waiting time (h) | Sample Weight (g) | Combustible Material (%) |
|-------|------------------|------------------|-------------------|--------------------------|
| FAISTPP | 750              | 1                | 20 g              | 7.5                      |
| MP    | 750              | 1                | 20 g              | 6.3                      |
| Lime  | 750              | 1                | 20 g              | 8.2                      |

Table 3. The tight BD values of FAISTPP, cement, MP and lime.

|       | FAISTPP | CEMI | MP | Lime |
|-------|---------|------|----|------|
| BD (g/cm³) | 1.20 | 1.36 | 1.01 | 1.30 |

Since the BDs of FAISTPP, cement, MP and lime used in the study were different from each other, weight basis was used to determine the mixture parameters. In the mixture calculation, TS EN 520+A1, TS EN 3234, TS EN 14190, TS EN 13950, TS EN 12859, TS EN 13279-1 and TS EN 13279-2 standards were used. In this study, various combinations were made by using FAISTPP, cement, MP and lime mixtures (FAISTPP+cement, FAISTPP+MP, FAISTPP+lime). Preliminary experiments were performed. According to TS EN 13279-2 standard, flow test was applied. According to TS EN 12390-5 standards, building panel specimens in 4x4x16 cm were produced.

The curing process was applied to all samples in fully saturated condition in water for 7 and 28 days. After curing time, CS tests were performed for FAISTPP+cement building panels. And more, the specimens prepared by using FAISTPP+MP were cured firstly at the room conditions and then they were also cured at 40 ºC in oven after 7 days for 24 hours. On the other hand, the specimens produced by mixing FAISTPP+lime were cured in room condition for 7 and 28 days. After that, CS tests were performed when they reached to constant weight. Porosity was determined for FAISTPP+cement building panels but could not performed in FAISTPP+MP and FAISTPP+lime specimens since water caused them poured.
FS and CS of building panels in 40x40x160 mm size prismatic specimens were tested according to ASTM C 348 and ASTM C349 at 7 and 28 days, respectively. The BD, WA and porosity of these panels were determined with respect to ASTM C642 at 28 days.

3. Results
In this study, with contribution of FA_{ISTPP}, building panels in the mixture of 10-100% of cement, MP and lime were produced. Mechanical and physical tests (FS, CS, BD, porosity and WA) of these panels were made (Table 4 and 5).

FS values of the cemented building panels incorporated with FA_{ISTPP} at 7-day and 28-day were determined the lowest in 10% cement+90% mixture (0.58 and 0.93 MPa), and the highest in 90% cement+10% FA_{ISTPP} mixture (10.2 and 15.1 MPa). In these building panels, the lowest CS values at 7 and 28 days (1.90 and 4.15 MPa) were found in 10% cement+90% FA_{ISTPP} mixture, whereas the highest (57.3 and 64.2 MPa) values were determined in 90% cement+10% FA_{ISTPP} mixture (Table 4).

In FA_{ISTPP}+MP building panels, the lowest and highest values (0 and 16.4 MPa) were determined in 90% MP+10%FA_{ISTPP} and 90% MP+10% FA_{ISTPP} combinations, respectively. In these building panels, the lowest CS value (0.99 MPa) for 7 days was determined in 50% MP+50% FA_{ISTPP} mixture and the highest CS value (6.80 MPa) was found in 90% MP+10% FA_{ISTPP} mixture (Table 4).

The FA_{ISTPP}+lime building panels were dissolved in 7 days. The lowest and highest FS values (0.42 and 0.87 MPa) were determined in the mixture of 70% lime+30% FA_{ISTPP} and 90% lime+10% FA_{ISTPP}, respectively, at 28-day. The lowest 7-day CS value (1.14 MPa) was found in 50% FA_{ISTPP}+50% lime mixture, and the highest CS value (1.12 MPa) was found in 70% lime+30% FA_{ISTPP} mixture. For 28-day, the lowest CS value (0.43 MPa) was determined in 70% FA_{ISTPP}+30% lime mixture, and the highest CS value (1.83 MPa) was determined in 90% lime+10% FA_{ISTPP} mixture (Table 4).

Table 4. FS ve CS test results of building panels produced by using FA_{ISTPP}+cement, FA_{ISTPP}+MP and FA_{ISTPP}+lime mixtures.

| CEMI (%) | FS (%) | CS (%) | MP (%) | FS (%) | CS (%) | Lime (%) | FS (%) | CS (%) |
|----------|--------|--------|--------|--------|--------|----------|--------|--------|
|          | 7-day  | 28-day | 7-day  | 28-day | 7-day  | 28-day   | 7-day  | 28-day |
| 10       | 0.58   | 0.93   | 1.90   | 4.15   | 10     | 0        | 0      | 10     |
| 30       | 3.10   | 6.80   | 10.60  | 25.30  | 30     | 0        | 0      | 1.30   |
| 50       | 7.20   | 9.80   | 21.60  | 39.90  | 50     | -0.99    | 4.57   | 50     |
| 70       | 7.57   | 12.60  | 34.80  | 46.10  | 70     | -3.91    | 8.36   | 70     |
| 90       | 10.20  | 15.10  | 57.30  | 64.20  | 90     | -6.80    | 16.40  | 90     |
| 100      | 12.53  | 18.03  | 67.43  | 75.42  | 100    | -8.13    | 19.68  | 100    |

In FA_{ISTPP}+cement combinations, BD values were found as 1.95 and 2.04 g/cm³ for building panel produced using 90% cement+10% FA_{ISTPP} mixture and 100% cement. The mixture with the highest porosity value (42.3%) was 90% cement+10% FA_{ISTPP}. The porosity value of building panel produced from 100% cement was 37.4%. The highest WA value (39.3%) was measured for FA_{ISTPP} mixtures in 10% cement+90% FA_{ISTPP} ratio. In the building panel produced from 100% cement, the WA value was measured as 26.1% (Table 5).
Table 5. BD, porosity and WA test results of building panels produced by using FA_{ISTPP}+cement, FA_{ISTPP}+MP and FA_{ISTPP}+lime mixtures.

| CEMI | BD (g/cm³) | Porosity (%) | WA (%) | MP | BD (g/cm³) | Porosity (%) | WA (%) | Lime | BD (g/cm³) | Porosity (%) | WA (%) |
|------|------------|--------------|--------|----|------------|--------------|--------|------|------------|--------------|--------|
| 10   | 1.61       | 37.4         | 39.3   | 10 | 1.07       | -            | 31.4   | 10   | 1.09       | -            | -      |
| 30   | 1.80       | 39.1         | 38.9   | 30 | 0.97       | -            | 45.1   | 30   | 1.18       | -            | -      |
| 50   | 1.86       | 36.2         | 37.2   | 50 | 1.02       | -            | 32.7   | 50   | 1.21       | -            | -      |
| 70   | 1.92       | 34.4         | 31.6   | 70 | 1.03       | -            | 26.8   | 70   | 1.24       | -            | -      |
| 90   | 1.95       | 42.3         | 28.5   | 90 | 1.23       | -            | 24.2   | 90   | 1.29       | -            | -      |
| 100  | 2.04       | 37.4         | 26.1   | 100| 1.24       | -            | 26.8   | 100  | 1.22       | -            | -      |

The highest BD value (1.23 g/cm³) for FA_{ISTPP}+MP mixture was found in the building panel specimen including 90% MP+10% FA_{ISTPP}. In the sample including 100% MP, the BD value is 1.24 g/cm³. Since porosity tests cannot be performed on building panels produced from FA_{ISTPP}+MPA, they are not given in Table 5. The highest WA value (45.1%) in FA_{ISTPP} mixtures was determined in the sample having 30% MP+70% FA_{ISTPP} mixture. WA value was 26.8% in the building panel produced with 100% MP.

On the other hand, the highest BD value (1.29 g/cm³) for FA_{ISTPP}+lime mixture was measured in 90% lime+10% FA_{ISTPP} and 80% lime+20% FA_{ISTPP} mixtures. The BD value of the building panel produced using 100% lime was 1.22 g/cm³ (Table 5). Since porosity and WA tests cannot be performed on building panels produced from FA_{ISTPP}+lime, they are not given in Table 5.

4. Discussion and Conclusion

In the study, CS values of FA_{ISTPP}+lime building panels were decreased when the lime ratio was decreased. It was observed that water was split off from the mold surface when it is poured into molds by compression. This situation increases porous and cracked structure by decreasing FS and CS values.

It has been found that the FS and CS values of the building panels produced using 100% MP are higher than those produced using FA_{ISTPP}. The use of MP and lime with FA_{ISTPP} have reduced the values of FS and CS. This situation leads to opinion that the use of lime and MP was not suitable for producing high strength building panels. There has been an increase in FS and CS values when cement amount increased and FA_{ISTPP} decreased. For FA_{ISTPP}+limestone building panels, CS values decreased when lime ratio decreased. On the other hand, as the FA_{ISTPP} amount increases in FA_{ISTPP}+MP building panels that there is a decrease in CS values. In the study of Kılınçarslan and Tuzlak (2018)[23], it was reported that the FA usage had a positive effect on the CS of foam concretes and stated that CS values increased in parallel with the increase in density. In their work, the scientists express that FA can be evaluated in foam concrete. In the present study, it was reported that BD values increase when the CS values of the building panels increase and FA_{ISTPP} can be used in the production of building panels. In this study, building panels produced by using FA_{ISTPP}+cement with less than 70% FA_{ISTPP} contributions and FA_{ISTPP}+MP with less than 50% FA_{ISTPP} contributions meet the related standards. In the study, reuse of FA_{ISTPP} to a building panel for the construction sector with the cleaner production principle was done. It is a study on industrial symbiosis. Since industrial solid waste (FA_{ISTPP}) is completely converted into product, it also supports the zero-waste philosophy. Having higher CS value is one of the most important features for building materials. The building panels produced in this study
have high CS and low BD values, so they offer high strength in lightweight building material. If serially produced, it is envisaged that it will contribute to the solution of the problem of solid waste, the economy and human health.

5. Acknowledgment
This study was presented in the 1st International Conference on Environment, Technology and Management (ICETEM). We thank Prof. Dr. Ahmet Bilgil for his valuable comment and contribution. The authors would like to thank ÇİMSA, one of the leading companies of Turkish cement industry, which supports this study and Dr. Adnan Güven, former manager of the ÇİMSA Niğde Plant. This work was partially supported by the project "Development of eco-friendly composite materials based on geopolymer matrix and reinforced with waste fibers" funded by the European Commission, within the 7th Framework Programme for Research and Technology Development (FP7), Topic #02: Waste management, recycling and urban mining (Project No. ELAC2015/T02-0721) under the ERANet-LAC: Latin America, Caribbean and European Union and supported by a grant of the Turkish Scientific and Technological Research Council of Turkey (TÜBİTAK). The Turkish project number is 116Y549.

References
[1] Ahmaruzzaman M 2010 Prog. En. Combustion Sci. 36 327-363
[2] Sonebi M 2002 Mater. Struct. 35 373-380
[3] Aitcin PC et al 1984 The use of condensed silica fume in grouts(innovative cement grouting, SP-83) American Concrete Institute, 1-18
[4] Ruggiero J G 1984 Low slump compactive tail shield grouting in soft ground shield driven tunnels(Innovative Cement Grouting, SP-83) American Concrete Institute, p. 103-114
[5] Weaver K D et al 1990 Concr. Int. 12 45-47
[6] Tsvilis S et al 1999 Cement. Concrete. Comp. 21 107-116
[7] Voglis N et al 2005 Cement. Concrete. Comp. 27 191-196
[8] Tsvilis, Set al 2002 Cement. Concrete. Comp. 24 371-378
[9] Dhir R K 2007 Construction. Mater. Struct. 40 459-473
[10] Rahhal, Vand Tolero R 2005 Cement. Concrete. Res. 35 1285-91
[11] Yahia A et al Cement. Concrete. Res. 35 532-539
[12] Poppe A M and Schutter G D 2005 Cement. Concrete. Res. 35 2290-99
[13] Bentz D P 2006 Cement. Concrete. Comp. 28 124-129
[14] What is Cement? History-Chemistry-Industries. In: Civil Engineering 2019. https://civiltoday.com/civil-engineering-materials/cement/81-cement-definition-and-full-details. Accessed 29 October 2019
[15] Moulding Plaster. In: ACG Materials 2019 https://www.acgmaterials.com/moulding-plaster/. Accessed 29 October 2019
[16] Baltar L M et al 2013 Int. J. Miner. Process. 125 5-9
[17] Vimmrova A et al 2014 Cement Concrete Comp. 52 91-96
[18] Plastering Applications. In: Graymonthttps://www.graymont.com/en/markets/building-construction/plastering. Accessed 29 October 2019
[19] Plastering Applications. In: Graymonthttps://www.graymont.com/en/markets/building-construction. Accessed 29 October 2019
[20] Kenny M and Oates T 2000 Lime and Limestone (Ullmann's Encyclopedia of Industrial Chemistry) ed Elvers B (Berlin)
[21] Boynton R S 1980 Chemistry and Technology of Lime and Limestone (New York: Wiley& Sons)
[22] Kilınçarslan Ş and Tuzlak F 2018 Investigation of strength and thermal conductivity properties of foam concrete with fly ash, Uluslararası Sürdürülebilir Mühendislik ve Teknoloji Dergisi 1 1-5 (in Turkish)