Mortar Based on Biomass Ashes from Araucanía Region

O Soto¹, N Goméz¹, C Manzur¹, A González¹

¹Department of Industrial Processes. Universidad Católica de Temuco. P.O. Box 15D. Temuco, Chile.

E-mail: agonzalez@uct.cl

Abstract. The COMASA S.A. power plant is located near Temuco and burns a high amount of residual biomass produced in the Araucanía region. However, the main problem associated with this plant is the transportation and disposal of fly ash (9 tons per week), a residue generated during the combustion of Boiler I. Currently, fly ashes from Boiler I are transported more than 200 km south, increasing transportation and final disposal costs. In this study, the development of a mortar based on fly ash from the combustion of biomass from COMASA S.A. was analysed at a pre-feasibility level. The experimental procedure consisted of (i) the physicochemical characterization of biomass fly ash, (ii) obtaining different test specimens (mortars) via the addition of different proportions of fly ash (10-35%) to cement, and (iii) obtaining the best specimen by analysing the requirements of mortars for construction purposes (Chilean Standard NCh 1037). The test specimens were subjected to determination of apparent density, compression resistance, water absorption capacity and moisture content. The laboratory results showed that the mortar obtained with the addition of 20% of fly ash has similar physical characteristics to mortars used for building blocks, proving capable of resisting up to 20 MPa. To analyse the viability of the production of construction blocks based on best specimen, market, technical and economic-financial studies were carried out, considering the reuse of at least 60% of the fly ash generated per year. The study concluded that the project was viable, evidencing the potential use of this residue for the manufacture of low-cost blocks, while minimizing the cost associated with residue handling.

1. Introduction

Coal-based thermal power plants are the main source of power generation worldwide [1]. Because of the detriment caused by coal burning to the environment and human health, in addition to the depletion of coal in the short term, biomass has tended to replace coal [2]. However, both fuels generate a high amount of fly ash during combustion, made up of particulate matter mixed with the exhaust gases. These residues provoke environmental problems associated with the presence of toxic elements such as Pb, Zn and As during their final disposal in landfills [3], therefore, remediation of fly ash has been a topic of great concern for decades. China, Europe and the United States lead and promote research and legislation on new uses for ash from coal and biomass combustion. They are constantly researching to find new and low-cost valorisation procedures [4]. In this sense, major applications of fly ash residue have been reported in agriculture, cement and concrete production, catalysis and paint [1, 3].
With regard to cement and concrete production, fly ash is used because of its binding property. This property depends on the presence of CaO and SiO2 in fly ash [1]. Under wet conditions, both substances react and form calcium silicate hydrates (mineral phases in concrete). Concrete based on fly ash has shown high strength and low permeability. On average, up to 35% of fly ash can be added to cement (m/m) [5].

In Chile, the forest biomass industry currently has a capacity of 900 MW for energy production. Of these, around 470 MW are injected into the Central Interconnected System (SIC) through 19 thermal plants [6]. The “COMASA S.A.” biomass thermal plant in the Araucanía region generates 46 MW of energy by means of two burning systems. In addition, the plant generates almost 30 ton/day of biomass fly ash, which must be removed daily by special trucks and transported to the nearest available landfill site (200 km away).

In Chile, biomass fly ashes are still considered to be a worthless residue, but their disposal involves associated transportation, operational, logistical and final disposal costs. In this context, it is important to evaluate a possible application of biomass fly ash. In general, biomass fly ashes present a high content of Si, Ca and Al [7]. The presence of these elements could turn biomass fly ashes into a potentially excellent material for the cement and concrete industry. This work aims to study the incorporation of biomass fly ash in cement-based formulations as a possible future use of this waste stream.

2. Materials and Methods

2.1. Materials
Fly ash from biomass combustion was sampled from boiler 1 of the COMASA S.A. thermal plant located in Lautaro, Araucanía region. Additional materials (Portland cement and PVC pipes) for the production of the mortars with different doses of biomass fly ash were purchased at commercial stores. Other materials used (such as desiccator and beakers) belonged to the laboratory.

A mass of 20 kg of fly ash from biomass combustion was dried at 105 °C, after which the sample was thoroughly screened to obtain a particle size smaller than or equal to 1mm.

2.2. Methods

2.2.1. Preparation of the mixture.
The mixtures were prepared using only waster, Portland cement and biomass fly ash. The study contemplated adding doses of 0%, 10%, 15%, 20%, 25%, 30% and 35% ash to the mixture. The mass ratio between water and Portland cement was determined using the Abrams cone settlement test to obtain adequate hardening of the mixtures [8, 9].

2.2.2 Preparation of mortar samples.
The mortars were prepared in accordance with Chilean standard NCh 1019 [9]. PVC pipes were used as moulds. The mixture was divided into three equal volumes and placed in three layers in the moulds. Each layer was pressed with a rod four times until the rod penetrated the mixture up to 2 cm. Once the mould was filled, it was closed and labelled, indicating the manufacturing date, sample number and percentage of ash used. The moulds containing the mixtures were stored between 16 °C and 27 °C for curing. During this stage, all moulds were covered with sawdust to prevent evaporation. After 20 h, the hardened mixture was removed from the mould without causing damage. Then the mass of the samples was recorded and after that, all samples were placed (buried) in wet sawdust (moisture=90%) for 7, 14 and 28 days.

2.2.3. Determination of physical parameters of the resulting mortars.
The bulk density of the resulting mortars was determined by water volume displacement, submerging the mortar samples in water for 2 min [10].
To measure compression resistance, a continuous load was applied, without shocks and at a constant speed until clear manifestations of cracking in the mortar samples were detected or until the press delivered its maximum load by recording the same pressure, expressed in Pa.

With regard to the determination of water absorption, the test mortar samples were immersed in water at a temperature between 15° and 25°C for 24 h until a constant mass was achieved. Before, during and at the end of the test, a record was kept of the mass of the mortar samples.

### 2.2.4. Preliminary technical, economic-financial evaluation.

To analyze the viability of the production of construction blocks based on best mortar sample, market, technical and economic-financial studies were carried out, considering the reuse of at least 60% of the biomass fly ash generated per year by COMASA S.A. This study included analyses of price, demand, offer, SWOT, net present value (NPV), profit-investment relation (Q), investment recovery period (R.P.) and internal rate of return (IRR).

### 3. Results and Discussion

#### 3.1. Results of the chemical characterisation of biomass fly ashes

The chemical composition of the biomass fly ash provided by COMASA S.A was determined by means of X-ray fluorescence (XRF) at the research laboratory of the Universidad de Chile. The results obtained are shown in table 1.

| Major elements (m/m %) | Minor elements g/kg |
|------------------------|----------------------|
| Si                     | 47.7                 |
| K                      | 17.5                 |
| Al                     | 12.4                 |
| Ca                     | 10.2                 |
| Fe                     | 6.3                  |
| P                      | 3.0                  |
| S                      | 1.1                  |
| Ti                     | 0.7                  |
| Mn                     | 0.5                  |
| Ba                     | 0.3                  |

The presence of Si, Al and Ca in biomass fly ash is important for the construction sector to produce mortars and concrete-based products, among others. A factor that needs to be considered for their use in the construction sector is their potential toxicity. However, biomass fly ashes were subjected to a leaching toxicity test in 2010, in accordance with the Chilean regulation for hazardous wastes [11] and the results indicated that biomass fly ash is not a hazardous residue.

#### 3.2. Preparation of the mixtures

Based on the Abrams cone test, all mixtures (cement, water and fly ash) proved to be docile. Nevertheless, as the dose of biomass fly ash increased, the docility of the mixture decreased. The number of samples obtained was 63. During the curing phase, at the beginning the samples differed in colour, with the biomass fly ash samples darker than those without ash. However, at the end of curing phase all samples displayed similar behaviour in both colour and surface appearance, indicating that the biomass fly ashes were successfully incorporated into the mixture (Figure 1).
Figure 1. Curing phase of the moulds (left) and mortar without biomass fly ash at 28 days (right)

3.3. Results of physical parameters of the resulting mortars.

The results of the bulk density of the specimens are shown in Table 2 for the different evaluated doses of biomass fly ash incorporated into the cement. The bulk density results showed a clear trend, whereby an increase in the incorporation of biomass fly ash resulted in a decrease of the bulk density. This tendency was not affected by the curing period. However, this result does not necessarily imply that some properties such as its physical resistance are affected. The bulk density of the selected dose will determine the weight of the block to be made, and it is convenient that this value be as low as possible as it will make the final product much lighter and with low thermal conductivity, thus enhancing its insulating capacity.

Table 2. Results of parameters of mortars obtained during 7, 14 and 28 days of curing

| Parameters          | Curing days | 0%    | 10%   | 15%   | 20%   | 25%   | 30%   | 35%   |
|---------------------|-------------|-------|-------|-------|-------|-------|-------|-------|
| Bulk density (kg/m³) | 7           | 1818.0| 1802.9| 1697.2| 1687.7| 1589.6| 1555.8| 1568.0|
|                     | 14          | 1818.2| 1802.8| 1696.9| 1688.1| 1589.7| 1555.6| 1567.9|
|                     | 28          | 1818.1| 1803.3| 1697.4| 1688.2| 1589.9| 1555.9| 1568.0|
| Compression resistance (MPa) | 7        | 19.6  | 19.6  | 15.6  | 14.7  | 11.7  | 10.5  | 8.8   |
|                     | 14          | 19.6  | 19.6  | 19.6  | 19.6  | 19.6  | 16.6  | 19.6  |
|                     | 28          | 19.6  | 19.6  | 19.6  | 19.6  | 19.6  | 19.6  | 19.6  |
| Water absorption (kg/m³) | 7         | 343.2 | 314.3 | 315.4 | 378.7 | 408.2 | 446.8 | 451.5 |
|                     | 14          | 343.9 | 312.4 | 312.9 | 370.2 | 404.6 | 440.1 | 443.0 |
|                     | 28          | 343.0 | 312.1 | 312.9 | 371.2 | 400.0 | 431.4 | 443.1 |

A manual press with a maximum load of 19.6 MPa was used in the compression test. The samples with biomass fly ash at 7 days of curing presented lower resistance to compression compared to mixtures without biomass fly ash (Table 2), but almost all samples withstood the maximum load at 28 days of curing. Only samples with doses higher than 25% of biomass fly ash behaved erratically (Figure 2) and showed cracks in the structure at 14 days of curing. These results are similar to those obtained by Rajamma et al. [7]. It is known that the longer cement is kept wet, the greater the resistance that can be obtained, thus it is expected that samples at 28 days should show the best results. Chilean construction standard NCh 1037 requires samples to withstand at least 5 MPa [12]. In this study, all samples withstood higher pressures, indicating that products made of these mixtures are suitable for the construction of lightweight structures.
With regard to water absorption, the results obtained from the 28th day of the curing process are indicated in Table 2, where it is detected that samples with biomass fly ash absorbed more water than those without. Water absorption was more predominant when samples were tested at 7 days of curing, but as time went by, the samples containing biomass fly ash decreased their water absorption capacity. In all cases, however, the samples with biomass fly ash absorbed more water than those without. This behavior is not desirable because construction products should be impermeable and non-porous. Nevertheless, this problem could be reduced with the incorporation of additives to the mixture before the curing phase.

3.4. Results of preliminary technical, economic-financial evaluation

Based on the experimental production of the mortar samples, a process diagram for the production of environmentally friendly blocks (Eco blocks) was proposed. Figure 3 shows the production of Eco blocks with dimensions of 20x20x40 cm. This product will be made from 75% Portland cement and 25% of biomass fly ash. Eco block is a product suited for use in low-cost housing construction, contributing to avoid contamination without affecting the quality of the product offered to the consumers.

The demand for Eco blocks depends directly on the amount of m² to be built. Annual demand of Eco blocks was forecast using Crystal Ball software. The results indicated that the production of Eco blocks will be able to supply 35% of total demand after 5 years. This process will be carried out gradually, covering from 18% (first year) to 35% (fifth year).

The Eco block plant is designed to have an ideal production rate of 960 block units per hour. The investment value and total costs to produce the Eco blocks will be about CLP 236,899,835 and CLP 209,393,561 (CLP = Chilean pesos), whereas the income could reach around CLP 425,671,870 per year.

In order to determine the most convenient level of project financing, three possible scenarios were evaluated, simulating debts of 0% (own capital), 40% and 60% of the total investment over a period of 8 years. Fees will be calculated using the French amortization method. According to the Chilean Superintendence of Banks and Financial Institutions, the current annual interest rate on loans depends on the amount in UF (a Chilean currency unit indexed according to inflation). For loans below 5,000 UF an interest rate of 19.98% is applied while for amounts equal to or greater than 5,000 UF the interest rate corresponds to 5.66%. As shown in Table 3, project financing with own capital does not prove to be the best option because the intention is to obtain greater profitability although it may be linked to moderate risk.
Table 3. Scenario analysis of Project financing through the main financial indicators

| FLOW     | NPV     | IRR | Q  | R.P. |
|----------|---------|-----|----|------|
| 0% debt  | CLP 514,860,851 | 49% | 2.17 | 2.73 |
| 40% debt | CLP 492,378,282 | 65% | 2.08 | 2.25 |
| 60% debt | CLP 537,960,693 | 92% | 2.27 | 1.52 |

It was observed that the financing scenario with a 60% credit presented better indicators, this is attributed to the fact that the interest rate is considerably lower than that obtained with a 40% credit.

A sensitivity analysis was carried out to determine how the main financial indicators are affected by variations in volume, production costs and sales price. Three scenarios were evaluated that include the following changes in the aforementioned variables.

- Pessimistic scenario: Due to increasing competition, the company is forced to reduce the sales price by 10% each year. In parallel with the greater number of bidders, the sales volume drops by 5% per year and variable costs increase by 10% due to market uncertainty.
- Most probable scenario: Production and income expenses are preserved.
- Optimistic scenario: Due to the absence of competitors, the company can increase the sale price by 5% each year because of growing demand and variable costs decrease by 10% due to optimization in the purchase of supplies.

Table 4 presents the sensitivity analysis in terms of the main financial parameters. Even placing the project in the pessimistic scenario with an upward trend in production costs and decrease in sales volume, it is observed that the net present value (NPV) continues to be positive and the period of recovery on investment is short. However, the relationship (Q) obtained between profitability and the investment amount is very low, since during the last years of the project the balance sheets would close with losses.

Table 4. Sensitivity analysis through main financial indicators

| FLOW                 | NPV     | IRR | Q  | R.P. |
|----------------------|---------|-----|----|------|
| Pessimistic          | CLP 55,948,160 | 39% | 0.24 | 2.15 |
| Most probable        | CLP 537,960,693 | 92% | 2.27 | 1.52 |
| Optimistic           | CLP 969,171,917 | 124% | 4.09 | 1.16 |

Obviously, in the most probable scenario and in the optimistic, the project is very attractive because the NPV increases considerably in both cases, CLP 537,960,693 for the most likely scenario and CLP 969,171,917 for the optimistic scenario.

To start operations at the plant, an initial investment of CLP 236,899,835 is required, an amount that will be financed by an 8-year bank loan with an annual interest rate of 5.66%. The remaining 40% of the investment will be the company’s own capital.

4. Conclusions

According to the results obtained, the use of biomass fly ash to produce mortars and structural blocks is possible. The products obtained displayed a similar behaviour to products without biomass fly ash. Moreover, the reuse of biomass fly ash contributes to avoid contamination of soil and groundwater, because lower amounts of this residue are disposed of in landfills.

In addition, the preliminary technical, economic-financial evaluation of the production of Eco blocks based on doses of 25% of biomass fly ash showed that the investment is convenient. The Eco blocks company could achieve acceptable economic profitability, since the net present value is positive (NPV>0) for all sensitivity scenarios evaluated and the profit-investment indicator (Q) is also adequate.
References

[1] IPCC: Intergovernmental Panel on Climate Change. (2018). El IPCC y el sexto ciclo de evaluación. Extracted on 08-2019. https://www.ipcc.ch/site/assets/uploads/2018/09/AC6_brochure_es.pdf

[2] Xu G., Shi X. (2018). Characteristics and applications of fly ash as a sustainable construction material: A state-of-the-art review. Resources, Conservation and Recycling 136: 95-109.

[3] Yao Z.T., Ji X.S., Sarker P.K., Tang J.H., Ge L.Q., Xia M.S., Xi Y.Q. (2015). A comprehensive review on the applications of coal fly ash. Earth-Science Reviews 141: 105-121.

[4] ACAA: American Coal Ash Association (2017). Production and use reports in 2017. Extracted on 07-2019. https://www.acaa-usa.org/publications/productionuserreports.aspx

[5] Yin K., Ahamed A., Isak G. (2018). Environmental perspectives of recycling various combustion ashes in cement production - A review. Waste Management 78: 401-416

[6] Emol (2018). De Norte a Sur: Revisa dónde y quiénes generan la electricidad que le da energía a Chile. Extracted on 07-2018. https://www.emol.com/noticias/Nacional/2018/02/08/894243/Revisa-donde-y-quienes-generan-la-electricidad-que-prende-Chile-de-Norte-a-Sur.html

[7] Rajamma R., Ball R.J., Tarelho L.A.C., Allen G.C., Labrincha J.A., Ferreira V.M. (2009). Characterisation and use of biomass fly ash in cement-based materials. Journal of Hazardous Materials 172: 1049-1060

[8] Norma Chilena NCh 1018. Hormigón- Preparación de mezclas para ensayos en laboratorio. Extracted on 01-2018. http://normastecnicas.minvu.cl/

[9] Norma Chilena NCh 1019. Hormigón-Determinación de la docilidad-Método del asentamiento del cono de Abrams. Extracted on 01-2018. http://normastecnicas.minvu.cl/

[10] Norma Chilena NCh 1564. Hormigón - Determinación de la densidad aparente del hormigón fresco. Extracted on 01-2018. http://normastecnicas.minvu.cl/

[11] Reglamento sanitario sobre manejo de residuos peligrosos (DS 148). Extracted on 10-2018. https://www.leychile.cl/Navegar?idNorma=226458

[12] Norma Chilena NCh 1037. Hormigón – Ensayo de compresión de probetas cúbicas y cilíndricas. Extracted on 01-2018. http://normastecnicas.minvu.cl/