Study of recycle spent brick lining as refractory castable product

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Abstract. Every year INALUM has produced around 500-1000 ton spent brick lining which placed in the dump yard. After it has been placed, it sells to the third party. Spent Brick lining which has been cleaned has no or little harmful content and some chemical composition can be utilized as a new product as the refractory application in INALUM. Some research proves that spent brick has some good mechanical properties if applied as concrete and INALUM’s spent brick production high enough to fulfill castable needs in INALUM in a year. The General flow process of castable making is sorting and drying, crushing and grinding, screening, mixing (with other aggregate and additive). With this general production, it’s predicted to produce earning after taxes (EAT) around IDR 678,232,000 per year.

1. Introduction

Refractories are ceramic materials that are designed to withstand a variety of severe service conditions, including high temperatures, corrosive liquids and gases, abrasion, and mechanical and thermal-induced stresses [1]. Refractories are used by a variety of companies, including metal, ceramic, cement and glass producers [1]. When refractory materials have reached the end of their service life, they will be replaced with new refractories that have been manufactured from virgin raw materials and the spent refractories as a result of pot dismantling are typically disposed of in a landfill wasting valuable natural resources [1].

The production of spent refractory material in INALUM was reported to be over 500-1000 tons for the year, INALUM should pay third party for further handling this spent refractory so that it is not harmful to the environment. In order to minimize cost and production of industrial waste, INALUM does some research for a few years until now to find the best way to recycle spent refractory material into a reusable product.

Some studies are found in the literature. A. Baradan and M. Nematzade (2017)[2] investigated the various engineering properties of concrete using crushed brick as coarse aggregate. The investigation was done by comparing the properties of brick aggregate with different amounts of addition. The result proved that by replacing coarse aggregate with spent crushed fire brick show equal mechanical properties with the new one [2]. F. Brunck and Dr Otto (1995)[3] investigated that the chemical composition of spent brick from baking furnace didn’t change even though it has been used in baking operation for a long time in any position such as anode side, intermediate side, and flue side [3]. On the other hand, spent brick from pot reduction at the position that reacts with the metal or adjacent to cathode block has a potential loss in chemical position because of increasing CaO, Na2O, and F content [4]. We
can not utilize it before diminish those harmful content. However, spent brick located on the first and second layer or far away from liquid metal potential contact in pot reduction recommended to utilize because have little contained CaO, Na2O, and F [4].

INALUM has produced several types of waste every year. Some of these wastes are classified as B3 and Non-B3. B3 waste contains harmful substances such as Na2O, Fluoride, and Cyanide which if left unchecked, can pollute the environment. Some research state that brick waste that is not contaminated with molten metal can be categorized as Non-B3 waste which still has some ingredients that can be reused as raw material for refractory.

2. Method
2.1. Castable needs in INALUM

Table 1. Application castable in INALUM.

| Place               | Pot Reduction and Ladle | Baking Furnace | Holding Furnace and Launder | Induction Furnace |
|---------------------|-------------------------|----------------|----------------------------|-------------------|
| Photo               |                         |                |                            |                   |
| Volume              | 200-260 ton/year        | 12 ton/year    | 18-20 ton/year             | 6 ton/year        |
| Types of Castable   | Ca-13 I, Ca-13 Ni       | C13AS          | C13AS, IC-11 HS            | SK-30             |
|                     | HC-AL, C13AS            |                | C-HAS, Castable            | Dry Vibe          |
|                     |                         |                | Gibram, Matriflo 84        | Minrosil          |

Based on table 2.1 the annual castable requirement in a year is 300 tons while the production of waste brick in a year is 500-1000 tons. It means that brick production is sufficient to meet the needs of castable in INALUM.

2.2. General flow process of castable making

General flow process of castable making such as:

- **Sorting**
  Sorting is done to separate spent bricks from impurities or other bricks that have been contaminated with molten metal. Sorting was also done to determine the type of waste brick used to simplify the calculation of the desired composition.

- **Crushing and Grinding**
  After sorting, used brick is typically crushed to liberate refractory aggregate from metal, slag or other impurities that may have penetrated the lining [1]. In this process, the old refractories are roughly crushed into pieces of 200-400 mm so they can easily be handled in the subsequent crushing with heavy-duty machinery. After that production is carried out with a ball mill to reduce the size until 20 mm or less and recover them according to their particle size.

- **Screening**
  Screening is used to ensure that material has been reduced to the appropriate size for liberation. Mesh size is decided according to the purpose of classification. The largest mesh sieve is set at the top stage while the smallest at the bottom, with the intermediate mesh sieves set between them to mesh size. Size needed as raw material divided into 3-5 mm, 1-3 mm, 0-1 mm and #325.

- **Mixing**
The raw material that has been classified is mix with other raw material and additive in the mixer for some time after that the castable product is born.

![Sorting and Drying](image1)

**Figure 1.** General flow process of castable making.

### 2.3. Material used

- **Spent Brick Lining**
  Use as coarse aggregate containing Al$_2$O$_3$ and SiO$_2$ as the main phase as a refractory characteristic with percentage < 60%. Product in Market: B-1, C-1, SK-32, SK-34, SK-36

- **Bauxite/ Calcined Alumina**
  As raw material with percentage 30-60%, on coarse aggregate use bauxite, on fine aggregate use calcined clumina. Has high alumina and stable at elevated temperature. Product in market: CA-5M, Bauxite 85, Bauxite 80, Tabular Alumina.

| No | Name    | Al2O3 (%) | Fe2O3 (%) | BD (g/cc) | CCS (MPA) | Refractoriness (°C) |
|----|---------|-----------|-----------|-----------|-----------|---------------------|
| 1  | 50% Al2O3 | 51        | 0.4       | 30.5      | 40        | 1350                |
| 2  | 60% Al2O3 | 54        | 4         | 38        | 60        | 1440                |
| 3  | 70% Al2O3 | 71        | 0.4       | 29        | 70        | 1700                |
| 4  | 80% Al2O3 | 40        | 2         | 38.5      | 50        | 1270                |

- **Calcium Alumina Cement**
  Serves as a binding material with percentage of 10-20%. In the presence of water, he will form hydrate calcium aluminate hydrate or calcium silicate hydrate which can harden at room temperature and high temperature [5]. But the addition of water also needs to be adjusted to the type of raw material because the excess water will form a lot of porosity which reduces mechanical properties like figure 3.2. Product in market: Cement Fondu, A-700, Secar 71.
Figure 2. Hydration scheme of CAC concretes with a. excess water and b. suitable water [5].

- Other Additive
  To get certain properties with percentage <5% such as the speed of installation, plasticity, dispersion, coagulation, and others. Product in the market: Citric Acid, Isopropyl Alcohol, Sodium Phosphates, Silica Fume.

2.4. Example of castable making composition calculation

| Raw Material       | Size (mm) | Percentage | AL2O3 | SiO2 | CaO | Fe2O3 |
|--------------------|-----------|------------|-------|------|-----|-------|
| Spent S K – 32     | 3-5       | 20.00%     | 30    | 6    | 60  | 12    | 0     | 0     | 2.5  | 0.5  |
| Brick              | 3-1       | 20.00%     | 30    | 6    | 60  | 12    | 0     | 0     | 2.5  | 0.5  |
|                    | 0-1       | 20.00%     | 30    | 6    | 60  | 12    | 0     | 0     | 2.5  | 0.5  |
| Bauxite 85         | 3-5       | 5.00%      | 82    | 4.1  | 10.5| 0.525 | 0     | 0     | 1.99 | 0    |
|                    | 1-3       | 5.00%      | 82    | 4.1  | 10.5| 0.525 | 0     | 0     | 1.99 | 0    |
|                    | 0-1       | 5.00%      | 82    | 4.1  | 10.5| 0.525 | 0     | 0     | 1.99 | 0    |
| Tabular Alumina    | #325      | 5.00%      | 99    | 4.95 | 0   | 0     | 0     | 0     | 0    | 0    |
| A-700              | 20.00%    | 51         | 10.2  | 0.4  | 0.08| 30.5  | 6.1   | 0     | 0    | 0    |
| Total              | 100.00%   | 45.45      | 37.655| 6.1  | 1.5 | 1.5   |

3. Cost and benefit Analysis

3.1. CAPEX

| No. | Description                | Price (IDR)  |
|-----|----------------------------|--------------|
| 1.  | Crushing                   | 100,000,000  |
| 2.  | Milling                    | 12,000,000   |
| 3.  | Siever                     | 30,000,000   |
| 4.  | Mixer                      | 70,000,000   |
| 5.  | Land and Building          | 1,400,000,000|
| 6.  | Installation (5% Total Equipment) | 64,000,000 |
|     | Total CAPEX                | 1,784,000,000|
3.2. **OPEX**

| No. | Description                  | Price (IDR/Year) |
|-----|------------------------------|------------------|
| 1   | Total Electricity            | 92,400,000       |
| 2   | Material                     |                  |
|     | Cement                       | 750,000,000      |
|     | Bauxite                      | 1,750,000,000    |
|     | Alumina                      | 700,000,000      |
| 3   | Employee salary              | 1,728,000,000    |
| 4   | Maintenance (15% CAPEX)      | 267,600,000      |
| 5   | Transportation (2% CAPEX)    | 35,680,000       |
|     | Total OPEX                   | 5,323,680,000    |

3.3. **Cash flow**

| No. | Description                  | Priced (IDR/Year)  |
|-----|------------------------------|--------------------|
| 1   | Total COST SAVING            | 6,300,000,000     |
| 2   | Total OPEX                   | 5,323,680,000     |
| 3   | Depresiation, 10% Capex      | 178,400,000       |
| 4   | Gross Profit                 | 797,920,000       |
| 5   | EBT (Earning Before Taxes)   | 797,929,000       |
| 6   | Taxed, 15% EBT               | 119,688,000       |
| 7   | EAT (Earning After Taxed)    | 678,232,000       |

3.4. **Feasibility analysis**

| No. | Description | Value      |
|-----|-------------|------------|
| 1   | NPV (DF 12%)| 640,394,701|
| 2   | IRR         | 17.39%     |
| 3   | PI          | 2.79       |
| 4   | PB          | 2.63       |

4. **Conclusion**

Some research proves that spent brick has some chemical composition that can be utilized as a new product and the product has good mechanical properties. Spent Brick production in Inalum (500-1000 ton/year) high enough to fulfill castable needs in Inalum (200-300 ton/year). General flow process castable production from spent brick lining is Sorting – Crushing/Grinding – Screening – Mixing – Castable Product. Raw Material Needs to produce castable are spent brick (Max 60%), bauxite/tabular alumina (30-60%), alumina cement (10-20%), other additive (<5%). There is potential margin when implement recycle spent brick for producing castable in Inalum.

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