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# Sintering Behavior of Red Ceramic Incorporated with Blast Furnace Sludge Waste

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## Introduction

Brazil has a relevant steelmaking industry, being the largest steel producer in Latin America and ninth position in the world ranking [1]. In 2025, the Brazilian steelwork industry produced 33.4 million tons of crude steel, contributing to economic and social development. However, the steelwork industry also generates a significant amount of polluting solid waste known as blast furnace sludge (BFS). BFS waste has been tested as an alternative raw material in the manufacture of red ceramics [2]. However, little attention has been paid to the sintering behavior of red ceramic incorporated with BFS waste.

## Objective

The main objective of this study is to investigate the sintering behavior of a red ceramic paste incorporated with BFS waste.

## Methodology

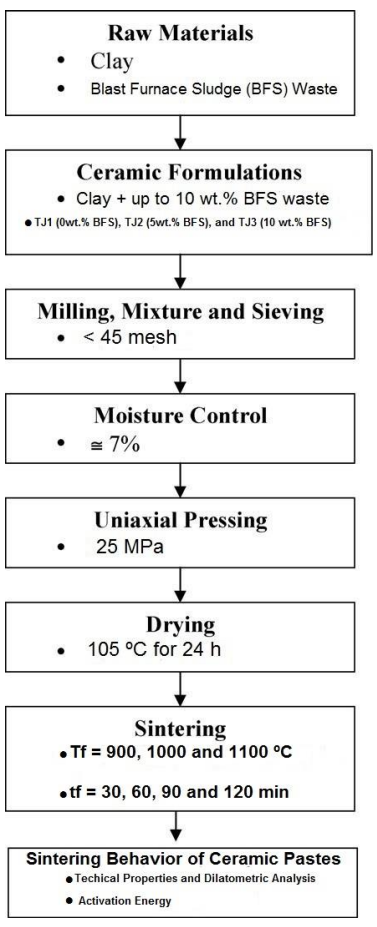



Figure 1. Flowchart of the experimental procedure

Table 1. Chemical composition of the raw materials (wt.%)

| Oxides | TJ1 | TJ2 | TJ3 | BFS waste |
|---|---|---|---|---|
| $SiO_2$ | 49.31 | 47.49 | 45.68 | 12.71 |
| $Al_2O_3$ | 27.02 | 25.93 | 24.86 | 5.19 |
| $Fe_2O_3$ | 7.70 | 8.28 | 8.85 | 19.11 |
| $K_2O$ | 1.89 | 1.89 | 1.88 | 1.78 |
| $Na_2O$ | 0.39 | 0.37 | 0.29 | - |
| CaO | 0.33 | 0.51 | 0.71 | 4.05 |
| MgO | 1.00 | 0.99 | 0.98 | 0.91 |
| MnO | 0.07 | 0.08 | 0.09 | 0.29 |
| $TiO_2$ | 1.38 | 1.32 | 1.26 | 0.16 |
| $P_2O_5$ | 0.17 | 0.18 | 0.18 | 0.33 |
| $SO_3$ | - | 0.15 | 0.29 | 2.92 |
| $Rb_2O$ | - | 0.11 | 0.23 | 2.29 |
| ZnO | - | 0.07 | 0.16 | 1.59 |
| PbO | - | 0.03 | 0.06 | 0.65 |
| Cl | - | 0.04 | 0.08 | 0.85 |
| F | - | 0.01 | 0.02 | 0.18 |
| LoI | 10.73 | 12.56 | 14.38 | 47.01 |

## Results and Discussion

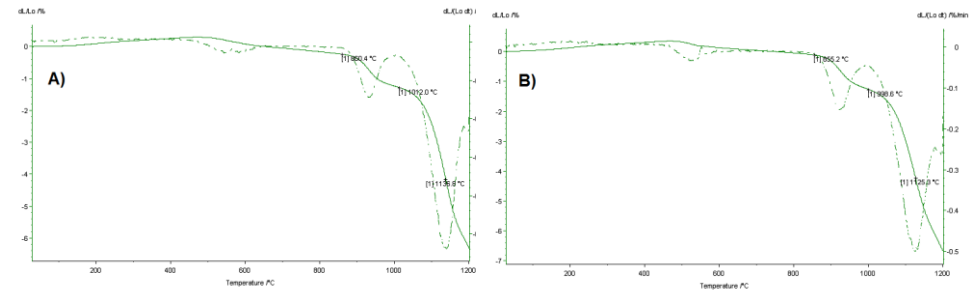



Figure 2. Dilatometric curves of the red ceramic formulations: A) TJ1 and B) TJ3

| Dilatometric Parameters | TJ1 | TJ3 |
|---|---|---|
| Start of Shrinkage | 860.4 °C | 855.2 °C |
| Start of Sintering | 1012.0 °C | 998.6 °C |
| Maximum Sintering Rate | 1136.8 °C | 1125.3 °C |

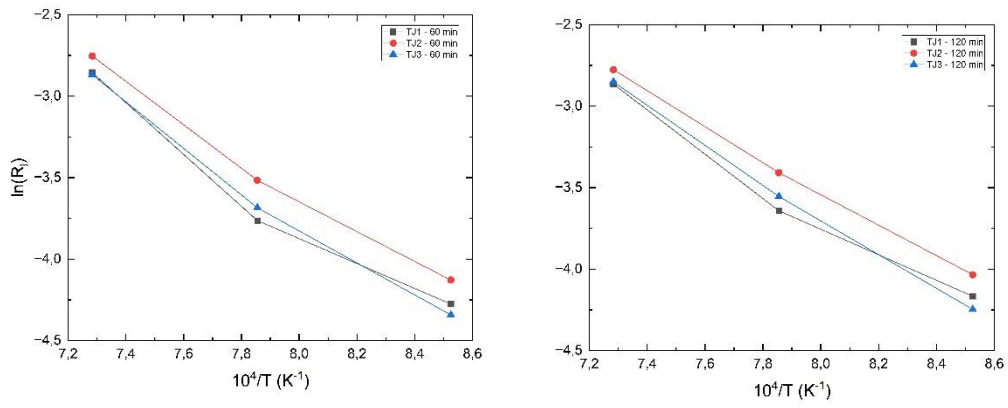



Figure 3. Determination of the activation energy.

| Formulation | Time (min) | Activation Energy (J/mol) | $R^2$ |
|---|---|---|---|
| TJ1 | 30 | 92670.3 | 0.6497 |
| TJ2 | | 91326.8 | 0.9655 |
| TJ3 | | 89185.1 | 0.8623 |
| TJ1 | 60 | 94288.2 | 0.9170 |
| TJ2 | | 91627.8 | 0.9766 |
| TJ3 | | 98242.4 | 0.9770 |
| TJ1 | 90 | 84940.0 | 0.9041 |
| TJ2 | | 81087.3 | 0.9578 |
| TJ3 | | 93280.6 | 0.9598 |
| TJ1 | 120 | 86562.0 | 0.9513 |
| TJ2 | | 84065.3 | 0.9953 |
| TJ3 | | 93300.5 | 0.9951 |

| Linear Shrinkage (%) | | | | |
|---|---|---|---|---|
| Sintering Temperature: 900 °C | | | | |
| Formulation | 30 min | 60 min | 90 min | 120 min |
| TJ1 | 1.38±0.27 | 1.39±0.29 | 1.61±0.33 | 1.55±0.21 |
| TJ2 | 1.44±0.24 | 1.61±0.10 | 1.82±0.31 | 1.77±0.11 |
| TJ3 | 1.35±0.12 | 1.30±0.15 | 1.39±0.18 | 1.43±0.17 |
| Sintering Temperature: 1000 °C | | | | |
| Formulation | 30 min | 60 min | 90 min | 120 min |
| TJ1 | 1.70±0.32 | 2.32±0.38 | 2.51±0.29 | 2.62±0.18 |
| TJ2 | 2.58±0.48 | 2.97±0.34 | 3.01±0.11 | 3.31±0.13 |
| TJ3 | 2.04±0.22 | 2.51±0.16 | 2.49±0.27 | 2.86±0.17 |
| Sintering Temperature: 1100 °C | | | | |
| Formulation | 30 min | 60 min | 90 min | 120 min |
| TJ1 | 5.67±0.17 | 5.76±0.28 | 5.80±0.07 | 5.70±0.28 |
| TJ2 | 5.68±0.23 | 6.37±0.15 | 6.16±0.07 | 6.23±0.29 |
| TJ3 | 5.20±0.22 | 5.68±0.11 | 5.65±0.09 | 5.78±0.20 |

| Apparent Density (g/cm³) | | | | |
|---|---|---|---|---|
| Sintering Temperature: 900 °C | | | | |
| Formulation | 30 min | 60 min | 90 min | 120 min |
| TJ1 | 1.75±0.01 | 1.74±0.03 | 1.77±0.03 | 1.75±0.03 |
| TJ2 | 1.69±0.03 | 1.71±0.02 | 1.71±0.04 | 1.72±0.02 |
| TJ3 | 1.65±0.02 | 1.65±0.01 | 1.64±0.02 | 1.65±0.03 |
| Sintering Temperature: 1000 °C | | | | |
| Formulation | 30 min | 60 min | 90 min | 120 min |
| TJ1 | 1.79±0.04 | 1.79±0.01 | 1.81±0.02 | 1.82±0.04 |
| TJ2 | 1.76±0.02 | 1.75±0.04 | 1.78±0.05 | 1.78±0.02 |
| TJ3 | 1.69±0.04 | 1.70±0.05 | 1.70±0.02 | 1.85±0.05 |
| Sintering Temperature: 1100 °C | | | | |
| Formulation | 30 min | 60 min | 90 min | 120 min |
| TJ1 | 2.03±0.03 | 2.04±0.05 | 2.03±0.05 | 2.04±0.04 |
| TJ2 | 1.94±0.05 | 2.00±0.05 | 1.97±0.06 | 2.01±0.02 |
| TJ3 | 1.84±0.02 | 1.88±0.03 | 1.88±0.02 | 1.86±0.02 |

## Conclusions

- The results showed that the BFS waste influenced the sintering behaviour of red ceramic formulation. The effect of sintering temperature was dominant compared to sintering time.
- The dilatometric curves indicated that the BFS waste tends to anticipate the sintering of red ceramic.
- The TJ3 Formulation (with 10 wt.% BFS) exhibited lower temperature values related to the start of shrinkage, start of sintering, and maximum sintering rate.
- The increased amount of BFS waste contributed to a reduction in the densification of red ceramic.
- It was found that linear shrinkage ranged from 1.30 to 6.37 %, apparent density from 1.64 to 2.04 g/cm³, and activation energy from 81087.3 to 98242.4 J/mol, depending on the sintering conditions.

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