# ALKALINE CHEMICAL ACTIVATION OF URBAN GLASS WASTES TO PRODUCE CEMENTITUOUS MATERIALS

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## Abstract

This is a preliminary work for evaluate the promising direction to reuse the recycled vitreous material by the alkaline activation than help to produce an alternative material with cementitious characteristic. NaOH and NaOH/$Na_2CO_3$ solutions were used like activation agents during the alkaline chemical activation of glass waste/blast furnace slag mixtures. The particle size of glass waste and nature of alkaline solution were analyzed to identify their influence on the mechanical properties. The NaOH/$Na_2CO_3$ solutions showed better performance to activate the blast furnace slag. The mechano-chemical process is an option for dissolve the glass waste in an alkaline solution. The alkaline solution formed with the glass waste will be use like alkaline activation agent for the blast furnace slag.

*Keywords: Waste glass, alkaline activation, cementitious materials.*

## INTRODUCTION

The last decades were very important time in the care of environment and natural resources because has taken an enormous importance to global level. The industrialized countries have formulated legislations that permit a better control and utilization of the waste produced in the cities. One of the waste that take great interest are the vitreous material, due to theoretically is possible their recycling in a 100%. The main consumer for the recycled vitreous material (cullet) is the glass manufactory industry. The glass waste material recycled has some requirements for the utilization in the manufacture of new products. The mains requirements are: chemical composition, cullet particle size, metallic impurities, and the glass color.

During 2008 the waste glass production in Spain was more than 1 million tones [1]. The waste glass recovery to develop new application directions is a very important goal for the environment conservation and global economy, only the 60% of the waste glass is reused by the industry.

The information presented in this work is the initial stage in a research with the goal of re-uses the glass waste materials by the alkaline chemically activation. NaOH and NaOH/$Na_2CO_3$ solutions were used like activation agents during the alkaline chemical activation of glass waste/blast furnace slag mixtures [2-3]. The particle size of glass waste and nature of alkaline solution were analyzed to identify their influence on the mechanical properties [4-5].

## EXPERIMENTAL

### Materials used

Two materials were selected to the alkaline chemical activation, glass waste and blast furnace slag. The reason for choosing the slag is to compensate in the chemical composition the low content of CaO and/or $Al_2O_3$ at the glass chemical composition. The chemical composition urban vitreous waste and the blast furnace slag used to prepare the mortars are given in Table 1. The samples were grinding in a ball mill, and the obtained particle size was separate in two: 90>X> 45 µm, X <45. The alkaline activators were a NaOH solution and NaOH/$Na_2CO_3$ ratio 50/50, both solutions containing 5% $Na_2O$ by slag mass.

### Variables of the process and tests

The variables considered in alkaline chemical activation were:

- Glass waste / slag ratio (% weight): 100/0, 70/30, 50/50, 30/70, and 0/100.
- Particle size distribution of glass waste: 90>X> 45 µm, X<45 µm.

- Activator solution type: NaOH and $NaOH/Na_2CO_3$ solutions.

Table 1. Chemical composition of waste glass and slag (% wt.).

| Particle size | 90>X*>45 (Type I) | 45>X (Type II) | Slag |
|---|---|---|---|
| $SiO_2$ | 71,19 | 72,04 | 35,34 |
| $Al_2O_3$ | 1,77 | 1,62 | 13,65 |
| $Fe_2O_3$ | 0,48 | 0,27 | 0,39 |
| MnO | 0,01 | - | - |
| MgO | 2,96 | 3,39 | 4,11 |
| CaO | 9,36 | 8,19 | 41,00 |
| $Na_2O$ | 11,81 | 12,11 | 0,01 |
| $K_2O$ | 2,33 | 2,32 | - |
| $TiO_2$ | 0,06 | 0,04 | - |
| $P_2O_5$ | 0,04 | 0,02 | - |
| Cr ppm | 209 | 179 | - |
| Ba ppm | 53 | 67 | - |
| Pb ppm | 31 | 6 | - |
| $SO_3^-$ | - | - | 0,06 |
| $S^{2-}$ | - | - | 1,91 |
| L.O.I | - | - | 2,72 |
| I.R. | - | - | 0,64 |

* Particle diameter mean of vitreous material

The specimens were prepared by mixing the materials to activate, in this case, glass waste and slag in different proportions, adding the alkaline solution. The mechanical strength has been measured using a prismatic probe. The molds of 1x1x6 cm are filled with the formed paste and produce a probe test. The liquid/solid ratio of all pastes was constant at 0.47. Before testing, all samples were cured 7 days at 25°C and 98% of RH. Some pastes were also studied by XRD and FTIR.

## RESULTS AND DISCUSSION

### Mechanical strength tests

The compressive strengths of the waste glass pastes mixtures activated with the NaOH and $NaOH/Na_2CO_3$ solutions are present in Fig. 1. According to the test results, the best compressive strength values of 27.7 MPa was obtained from the pastes made of 30/70 waste glass/slag and activated with $NaOH/Na_2CO_3$, which represents a decrease in the compressive strength of up 2.25% as compared to the control mix (100% Slag).

The low compressive strength values of the pastes with high waste glass content could be attributed to the glass cannot be activated by the alkaline solution under the work conditions in this preliminary research. The mechanical strength is an effect of the reaction product of the slag activation [2-3, 6].

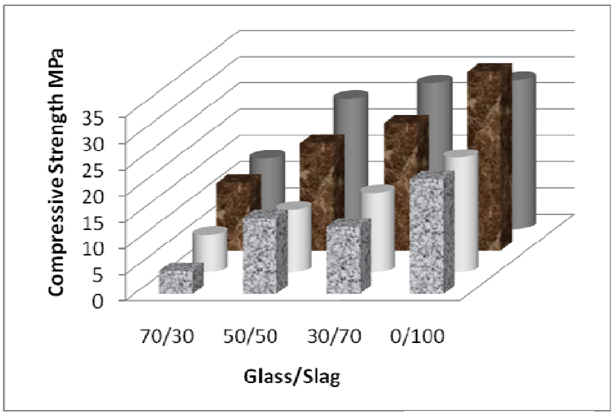


Figure 1. Compressive strength: Type I - NaOH, Type II - NaOH, Type I - (NaOH/Na2CO3), Type II - (NaOH/Na2CO3).

The flexural strength tests are present in the Fig. 2. Generally, the flexural strength was observed to follow the same trend for the waste glass mixes; the flexural strength tends to decrease as the waste glass proportion increased.

According to the test result, the 30/70 flexural strength values were observed to have a tendency to increase when the slag content was increased.

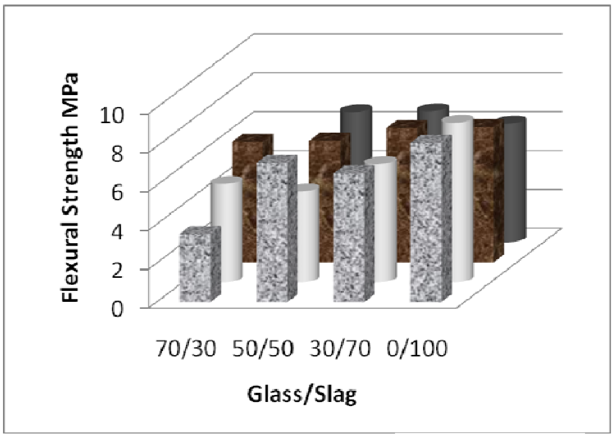


Figure 2. Flexural strength: Type I - NaOH, Type II - NaOH, Type I - (NaOH/Na2CO3), Type II - (NaOH/Na2CO3).

The use of $NaOH/Na_2CO_3$ solution like activator promotes a better mechanical performance in the mechanical test, 4% in the flexural strength, and 23% in the compressive strength. This shows that the alkaline solution have a very important role in the mechanical development [3].

The particle size of waste glass (in the conditions used in this work) has not influence in the mechanical strength, but according to several authors [4, 7], the waste glass powder has a pozzolanic behaviour after 28 days of curing, so it is necessary obtain that values of curing for analyzed the influence of the particle size in the alkaline activation process.

## X Ray Diffraction analysis

The phase analysis was conducted on samples treated with NaOH. In the Fig. 3 is given the difractogram of several samples of pastes. The C-S-H gel is identified in the difractograms, its main reflexions are located at $2\theta = 7.07^{o}, 29.09^{o}, 31.96^{o}$ y $49.83^{o}$ [8]. Also, It is possible identify other phases like Akermanite $Ca_2Mg(Si_2O_7)$, hydrotalcite $Mg_6Al_2(CO_3)(OH)_{16}$, calcite $CaCO_3$ and $\alpha$-$SiO_2$ Quartz traces.

The data shows the formation of C-S-H due to the alkaline activation of the slag in all the pastes mixtures. The slag in the pastes mixtures is the component capable to produce C-S-H gel because the glass waste has not the calcium content necessary for the C-S-H formation, and the glass it is not activated by the alkaline solution [8].

It is possible said that when the slag content enhance in the sample increase the material available for the alkaline activation.

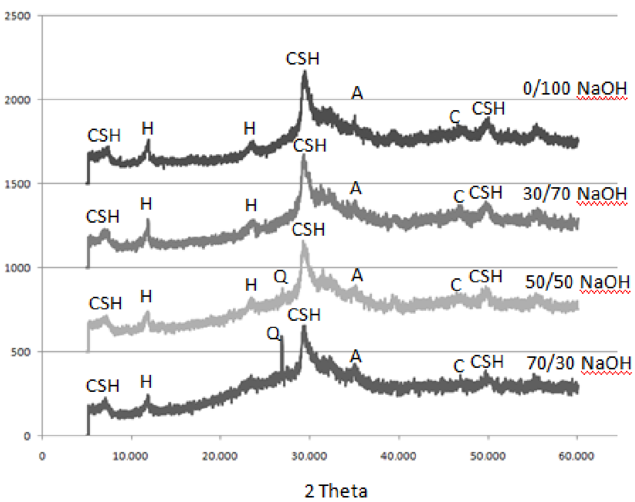


Figure 3. Difractogram of glass waste/slag pastes (CSH = Gel C-S-H, H = Hydrotalcita, A = Akermanite, Q = Quarzo, C = Calcite).

## Infrared analysis

Fig. 4 shows FTIR spectra of the samples activated with NaOH solution. The FTIR study detects a peak at 960 $cm^{-1}$ attributed to $v_3$ Si-O asymmetric stretching vibration of the tetrahedron silicate.

The band at 452 $cm^{-1}$ is attributed to $v_4$ Si-O out-of-plane-bending vibration [3, 8]. The band located at 1412 $cm^{-1}$ is assigned to the $CO_3^{2-}$ asymmetric vibration. Between 600-800 $cm^{-1}$ is located the band attributed to Al-O asymmetric stretching vibration of the $AlO_4$ groups in the slag.

The Table 2 shows the IR band position for the Si-O asymmetric stretching vibration of the silicate, and by the place where is the band located belong to the alkaline activated paste, to the C-S-H gel formation.

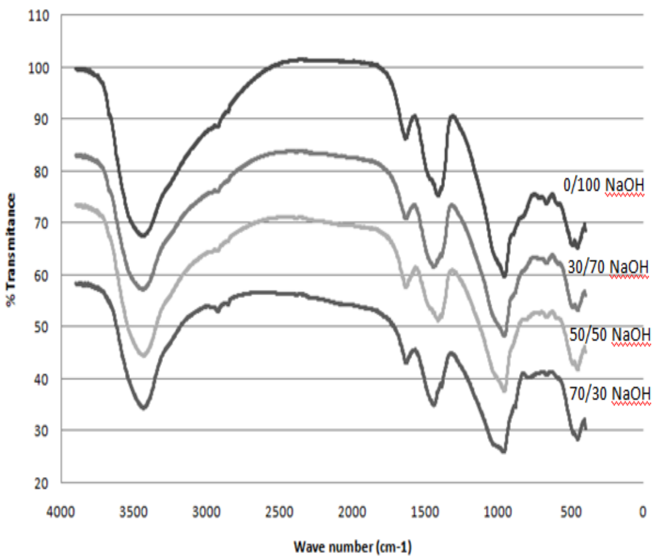


Figure 4. IR spectra of mixture paste of glass waste/slag activated with NaOH solution.

It is possible see how the band position change with high slag content in the paste mixture. The band moved its position to low values, and close to 970-960 $cm^{-1}$, this behaviour confirms the C-S-H gel formation.

Table 2. Evolution of FTIR spectra for the $\nu_3$ Si-O vibration.

| | Wave number $cm^{-1}$ ( $\nu_3$ Si-O) |
|---|---|
| Anhydrous Slag | 985.4 |
| Anhydrous glass waste | 1084.9 |
| 70/30, NaOH | 969.9 |
| 50/50, NaOH | 964.4 |
| 30/70, NaOH | 964.3 |
| 0/100, NaOH | 958.9 |

## CONCLUSIONS

The following main conclusions were derived from this work:

- The mechanical strength (Flexural and compressive) decrease when the glass waste content increase.
- Using the $NaOH/Na_2CO_3$ solution increase more than 20% the compressive strength values.
- The particle size has not influence on the mechanical strength in the condition of this work.
- The glass waste has a resistance to the alkaline chemical activation, so the use of mechano-chemical activation and temperature is the obvious next step to find an effective way to re-use urban glass waste.

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