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8th International Conference on Sustainable Solid Waste Management

23-25 JUNE 2021

# Geopolymers based on different types of slags. Comparison in terms of reactivity and mechanical properties developed.

M.A. Gómez-Casero, L. Pérez-Villarejo, P.J. Sánchez-Soto, D. Eliche-Quesada

*Department of Chemical, Environmental, and Materials Engineering, Higher Polytechnic School of Jaén, University of Jaén, Campus Las Lagunillas s/n, 23071 Jaén, Spain*

*email: mgomez@ujaen.es*

# INTRODUCTION

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Portland cement manufacture

$CO_2$

**Alkali-activated materials**

**Geopolymers**

Good results

Mechanical strength and Durability

Depends on

Material used

- Industrial waste
- Ashes
- Slags
- Natural sources

target

$CO_2$

# INTRODUCTION

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**Slags as precursor**

Several origin →

- Ground granulated blast furnace slag (black steel slag)
- Secondary metallurgical slag (white slag)
- Basic oxygen furnace slag
- Other slags (Lancellotti et al, 2021)

In this work ↓

**Black Steel slag (BSS) & Copper slag (CS)**

← Main chemical components

- BSS: CaO, $SiO_2$ and $Fe_2O_3$
- CS: FeO, $Fe_2O_3$

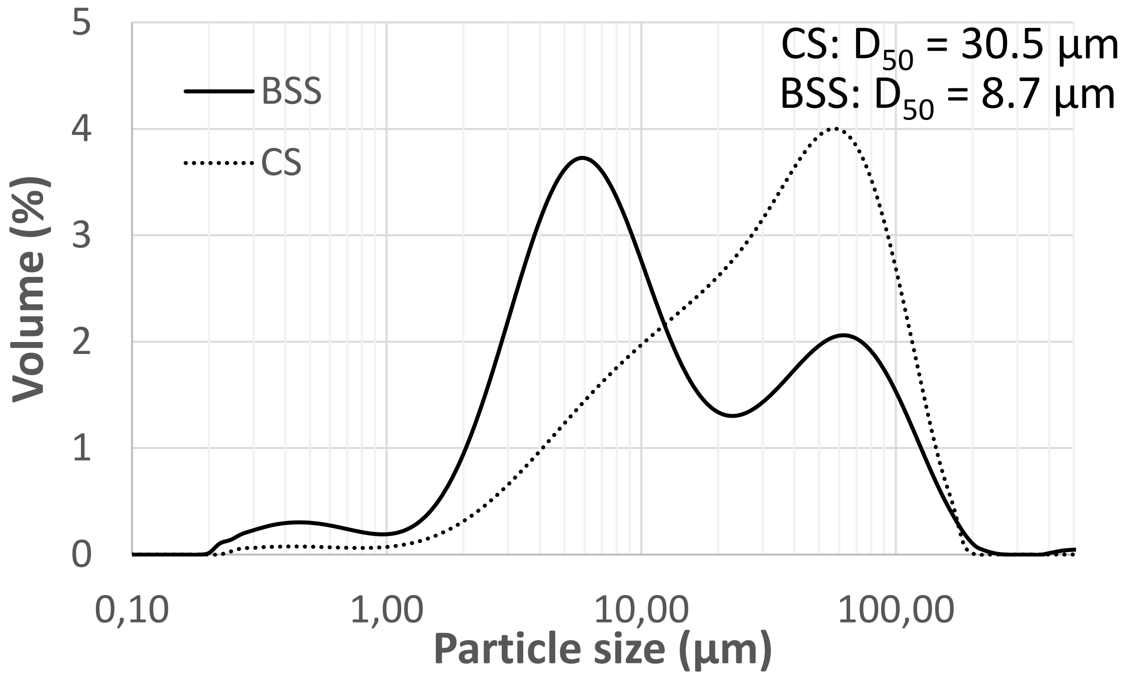
# MATERIALS AND METHODS



## RAW MATERIALS

**Black Steel slag (BSS)** from Siderúrgica Sevillana S.A. (Sevilla, Spain)

**Copper slag (CS)** from Atlantic Copper Fundición and Refinería (Huelva, Spain)



# MATERIALS AND METHODS

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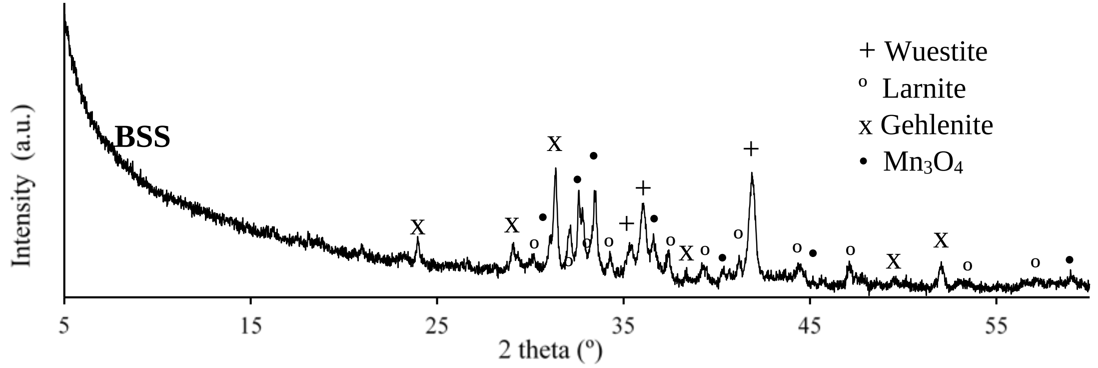
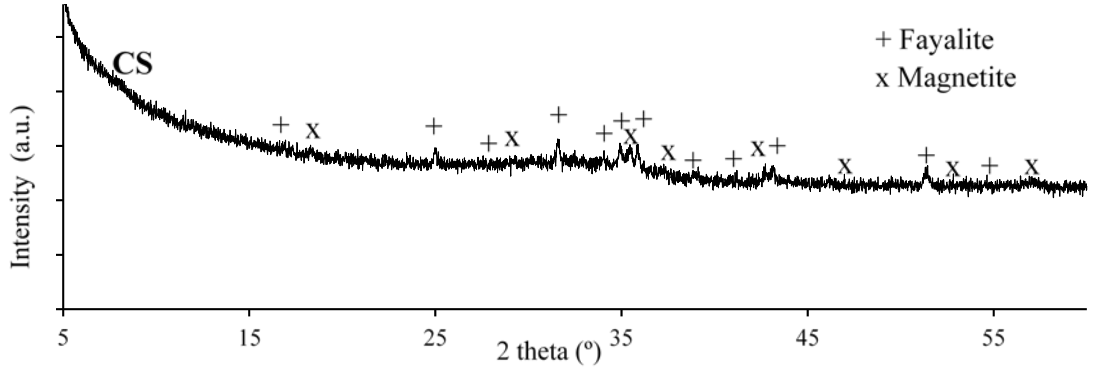
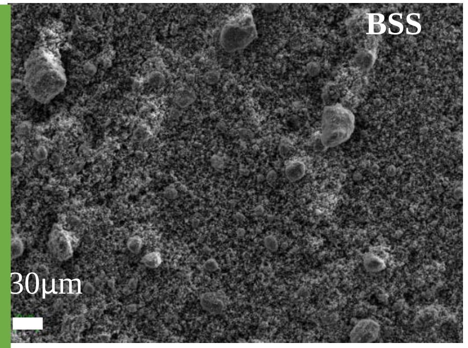
## RAW MATERIALS

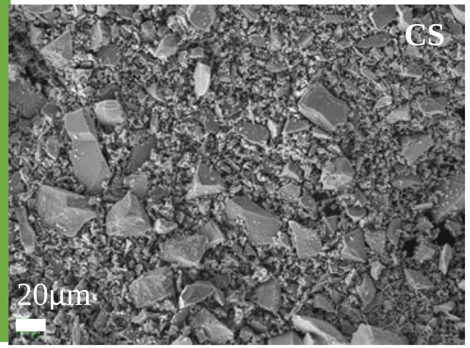
XRD




SEM




XRF

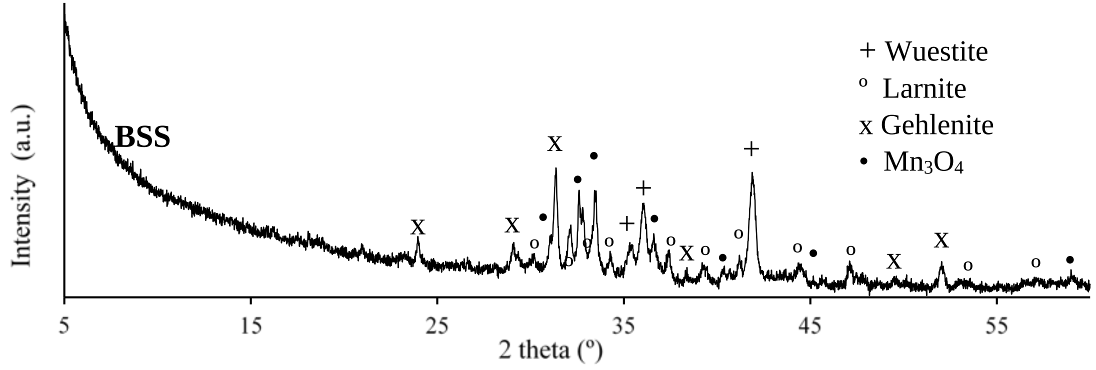
| Precursor | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | MnO | $Na_2O$ | $K_2O$ | $TiO_2$ | $P_2O_5$ | $SO_3$ | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BSS | 17.29 | 10.71 | 24.16 | 30.89 | 2.63 | 5.68 | 0.16 | 0.03 | 0.79 | 0.41 | 0.28 | 5.39 |
| CS | 27.65 | 2.04 | 62.18 | 1.25 | 0.38 | 0.03 | 0.63 | 0.56 | 0.21 | 0.04 | 0.9 | 0.00 |

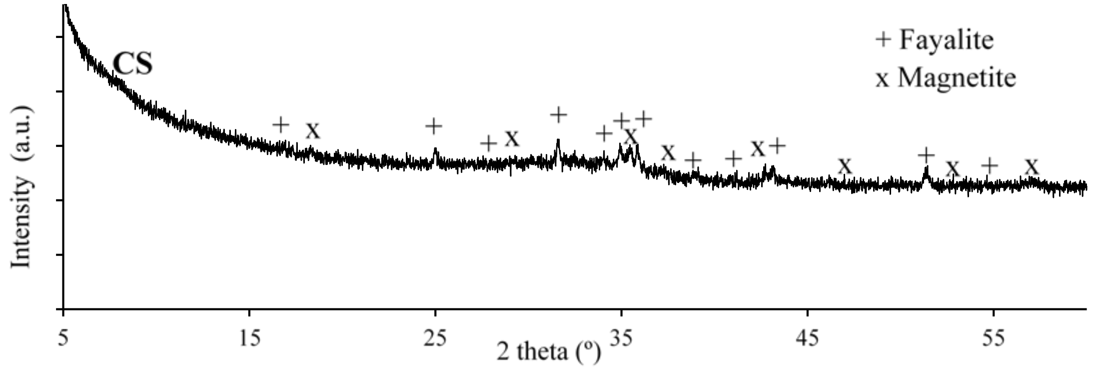
# MATERIALS AND METHODS



## RAW MATERIALS

**XRD**

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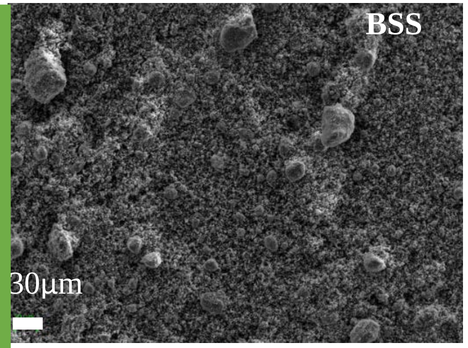


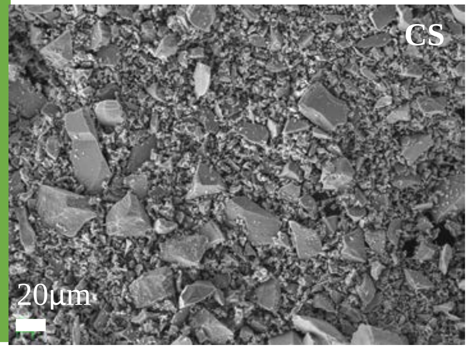


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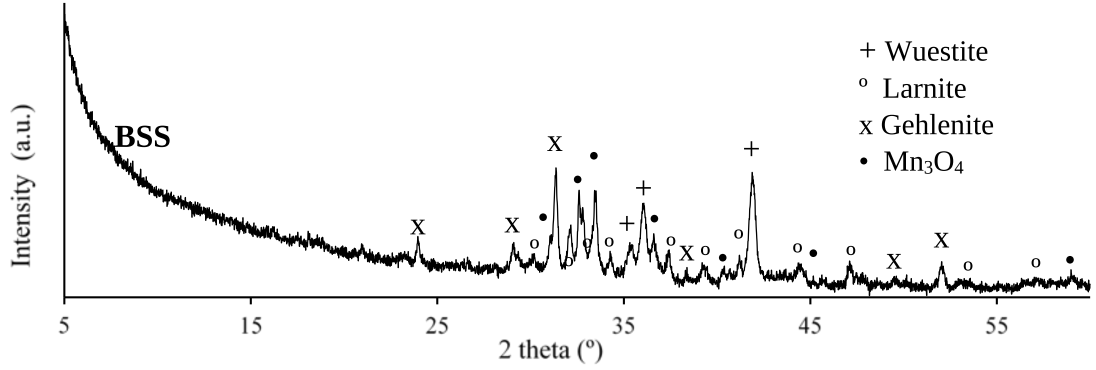
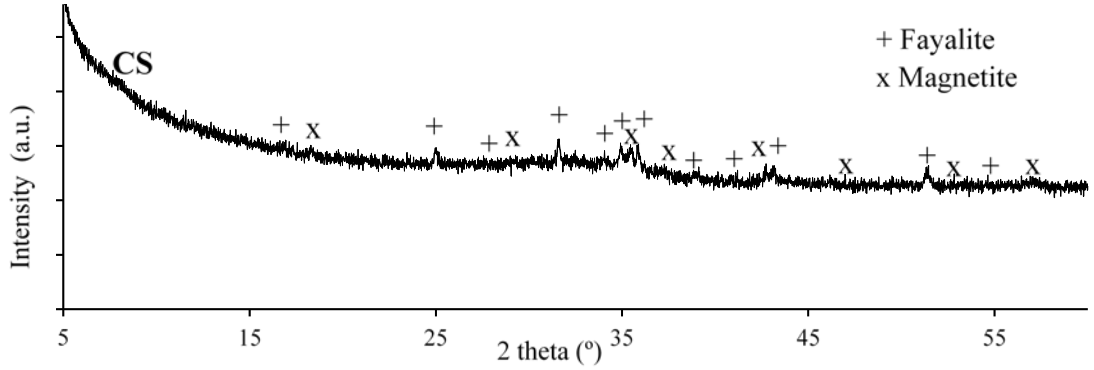
# MATERIALS AND METHODS



## RAW MATERIALS

**XRD**

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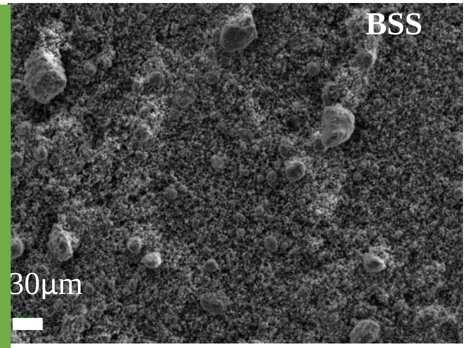


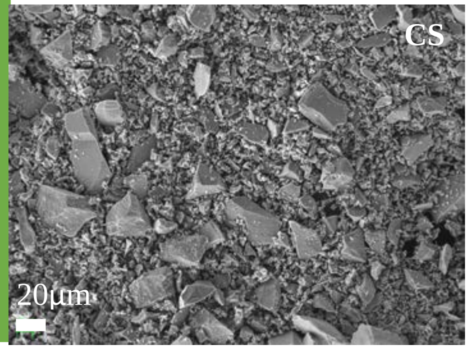


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# MATERIALS AND METHODS

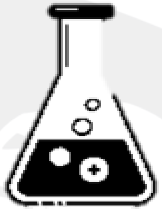


## MANUFACTURE OF BINDERS

Precursor

+

Activator solution



65% $K_2SiO_3$
+
35% KOH

| KOH molar ratio | Ms |
|---|---|
| 5M | 1.70 |
| 8M | 1.38 |
| 12M | 1.17 |
| 15M | 1.08 |

poured

Climatic chamber

20 ºC – 90 % RH

7, 28 and 90 days

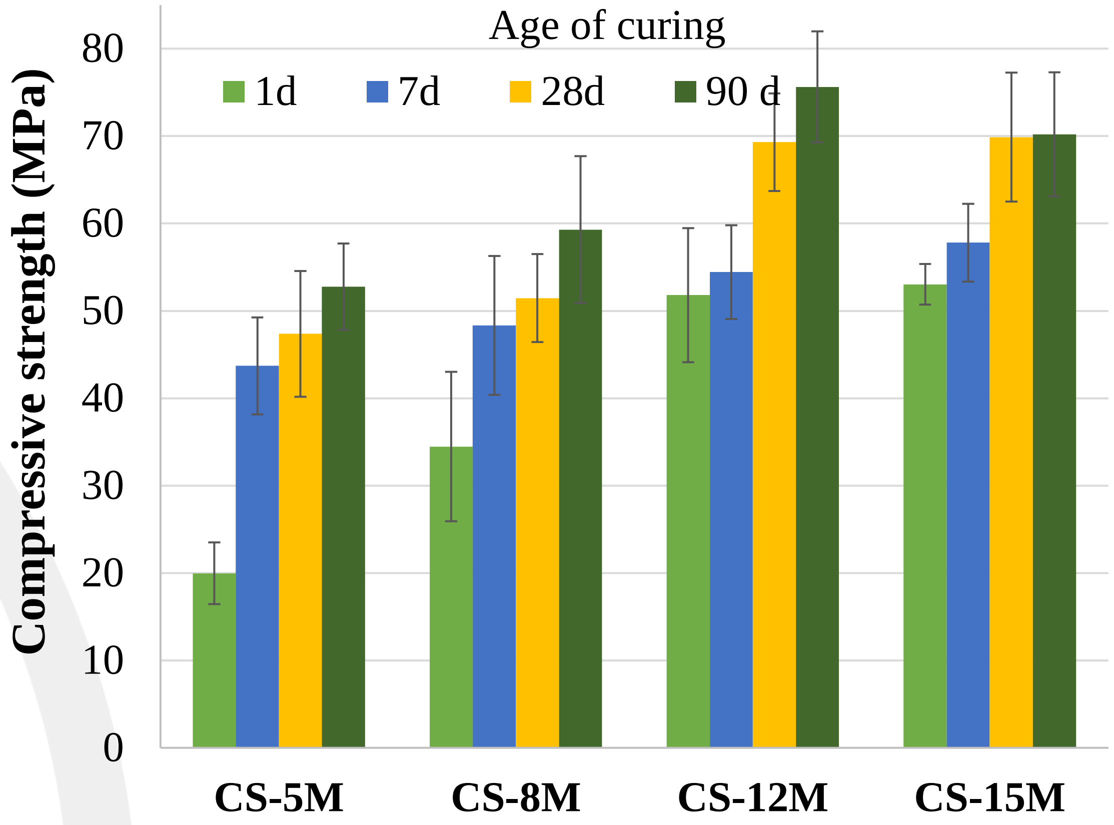
# RESULTS AND DISCUSSION

## MECHANICAL STRENGTH

**Compressive strength**

**BSS**


**CS**



# RESULTS AND DISCUSSION

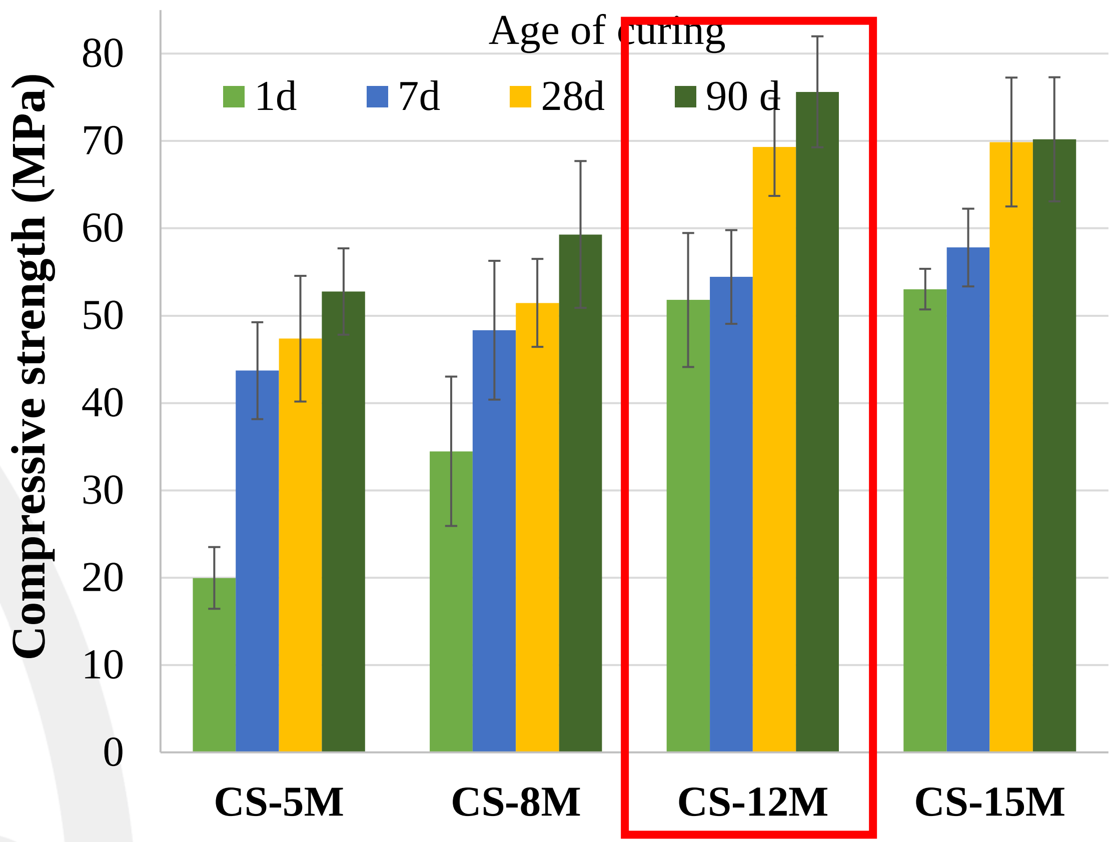


## MECHANICAL STRENGTH

**Compressive strength**

**BSS**


**CS**

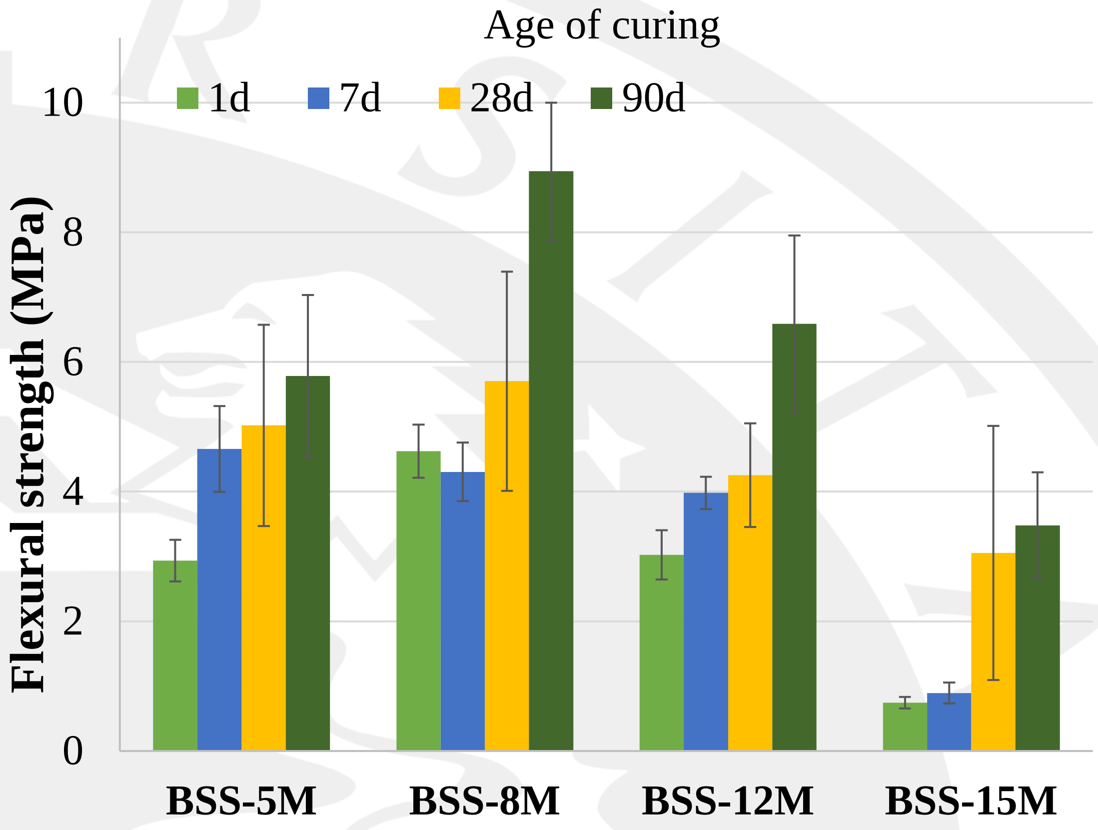


# RESULTS AND DISCUSSION

## MECHANICAL STRENGTH

### Flexural strength

**BSS**

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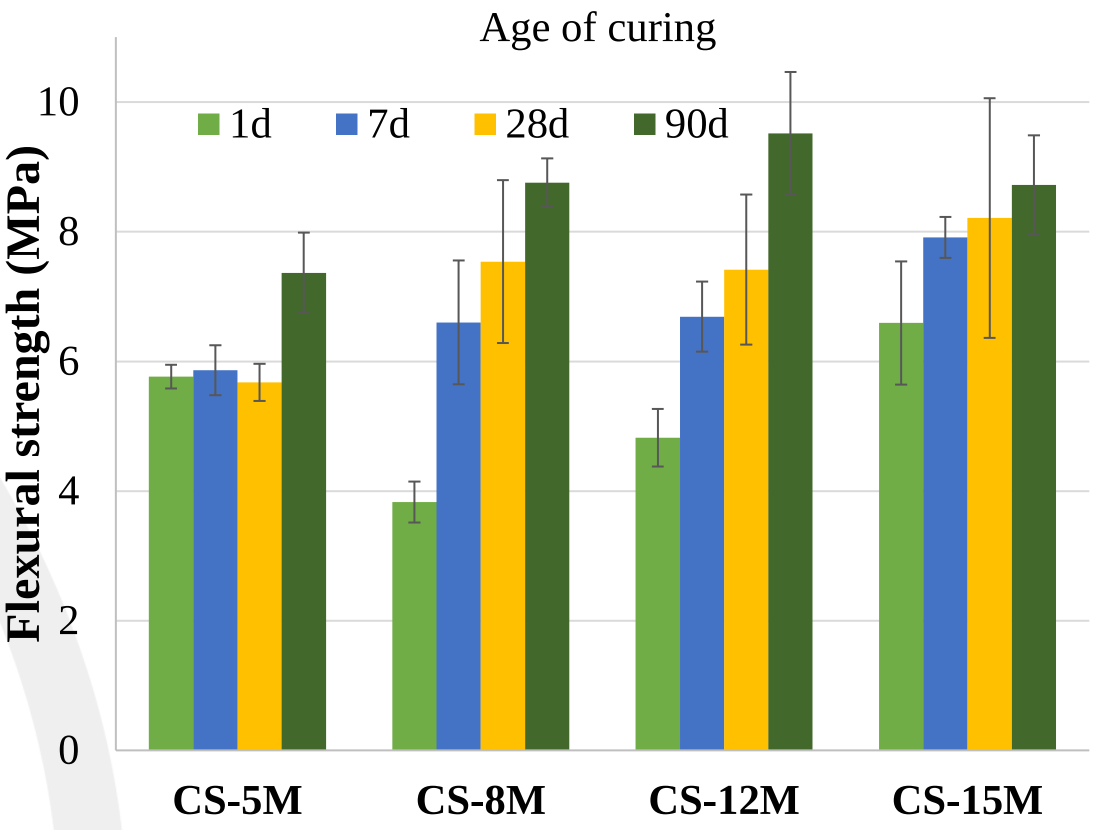


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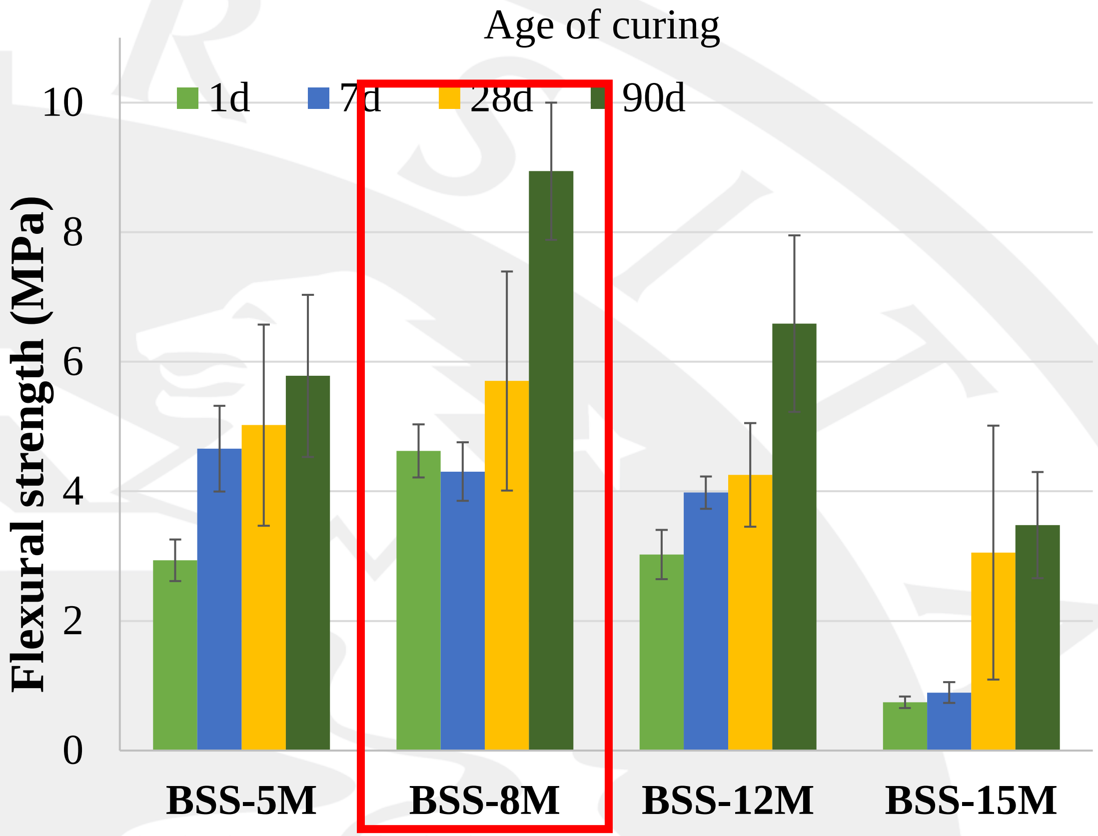
# RESULTS AND DISCUSSION

## MECHANICAL STRENGTH

**Flexural strength**

**BSS**

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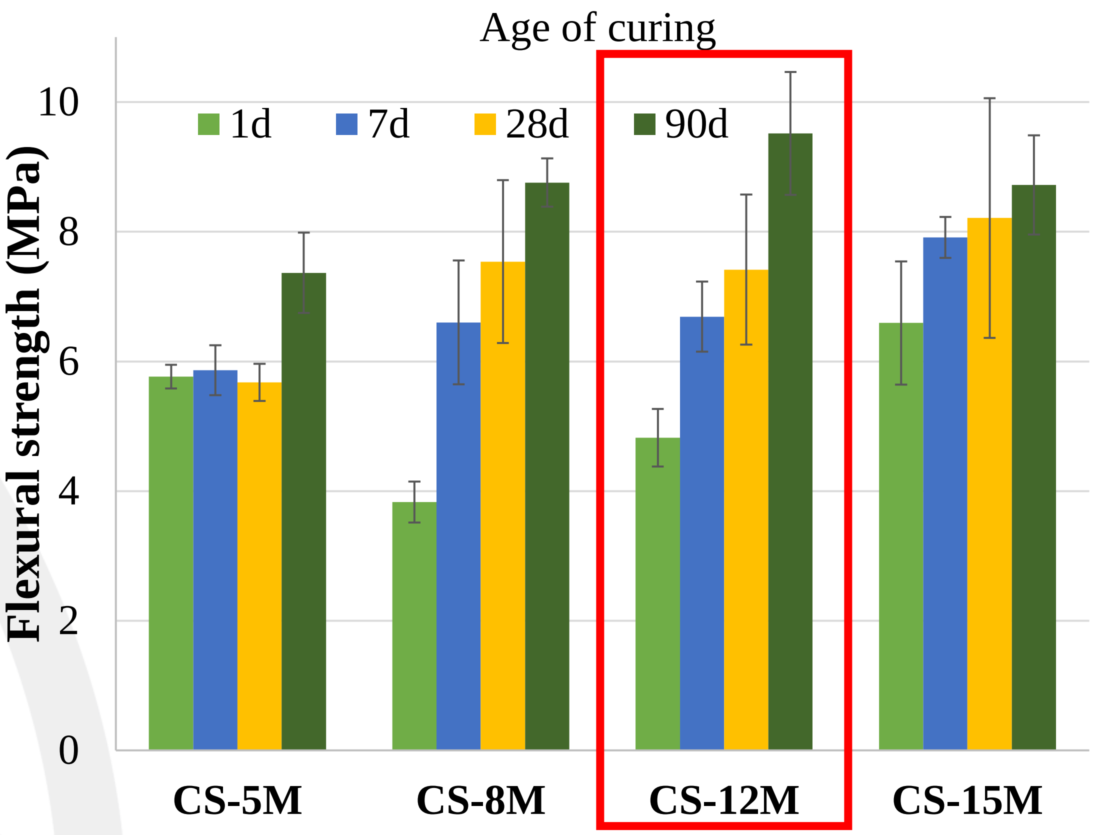

# RESULTS AND DISCUSSION



## PHYSICAL PROPERTIES

**BSS**

| a) | Age | BSS-5M | BSS-8M | BSS-12M | BSS-15M |
|---|---|---|---|---|---|
| BULK DENSITY (kg/m³) | 1d | 1719 ± 17.8 | 1739 ± 22.7 | 1700 ± 14.0 | 1702 ± 5.4 |
| | 7d | 1784 ± 17.9 | 1836 ± 24.0 | 1734 ± 11.7 | 1742 ± 5.1 |
| | 28d | 1828 ± 9.1 | 1884 ± 25.3 | 1781 ± 15.5 | 1769 ± 14.7 |
| | 90d | 1865 ± 15.5 | 1914 ± 19.3 | 1854 ± 51.2 | 1784 ± 13.9 |
| APPARENT POROSITY (%) | 1d | 39.49 ± 0.5 | 41.15 ± 0.5 | 39.28 ± 0.8 | 34.84 ± 0.2 |
| | 7d | 34.75 ± 0.8 | 39.98 ± 0.4 | 37.82 ± 2.1 | 33.61 ± 0.1 |
| | 28d | 33.07 ± 0.4 | 36.75 ± 0.7 | 33.75 ± 0.8 | 33.00 ± 0.4 |
| | 90d | 32.27 ± 0.7 | 27.80 ± 0.6 | 31.18 ± 0.5 | 32.92 ± 1.0 |
| WATER ABSORPTION (%) | 1d | 22.93 ± 0.4 | 24.15 ± 0.5 | 22.59 ± 0.7 | 20.66 ± 0.2 |
| | 7d | 18.89 ± 0.6 | 23.01 ± 0.4 | 21.16 ± 1.3 | 19.25 ± 0.1 |
| | 28d | 17.51 ± 0.2 | 18.67 ± 0.9 | 18.43 ± 0.7 | 18.41 ± 0.1 |
| | 90d | 16.82 ± 0.5 | 14.80 ± 0.3 | 16.68 ± 0.4 | 16.66 ± 0.7 |

**CS**

| b) | Age | CS-5M | CS-8M | CS-12M | CS-15M |
|---|---|---|---|---|---|
| BULK DENSITY (kg/m³) | 1d | 2670 ± 10,8 | 2677 ± 15.3 | 2742 ± 8.9 | 2716 ± 15.7 |
| | 7d | 2675 ± 26,3 | 2682 ± 4.6 | 2742 ± 7.2 | 2723 ± 11.3 |
| | 28d | 2696 ± 10,8 | 2707 ± 36.3 | 2744 ± 9.3 | 2728 ± 10.3 |
| | 90d | 2700 ± 27,7 | 2714 ± 12.2 | 2749 ± 17.4 | 2740 ± 12.7 |
| APPARENT POROSITY | 1d | 20.85 ± 0,3 | 21.71 ± 0.7 | 18.75 ± 0.5 | 19.76 ± 0.3 |
| | 7d | 20.35 ± 0,7 | 20.25 ± 0.2 | 18.15 ± 0.3 | 19.18 ± 0.2 |
| | 28d | 20.14 ± 0,6 | 18.73 ± 0.8 | 17.89 ± 0.2 | 18.77 ± 0.4 |
| | 90d | 19.39 ± 1,0 | 18.40 ± 0.1 | 17.46 ± 0.4 | 18.02 ± 0.8 |
| WATER ABSORPTION | 1d | 7.77 ± 0,1 | 8.11 ± 0.3 | 6.86 ± 0.2 | 6.98 ± 0.2 |
| | 7d | 7.58 ± 0,3 | 7.56 ± 0.1 | 6.67 ± 0.1 | 6.83 ± 0.1 |
| | 28d | 7.41 ± 0,2 | 6.93 ± 0.4 | 6.56 ± 0.1 | 6.54 ± 0.2 |
| | 90d | 7.15 ± 0,4 | 6.80 ± 0.1 | 6.36 ± 0.1 | 7.18 ± 0.3 |

# RESULTS AND DISCUSSION

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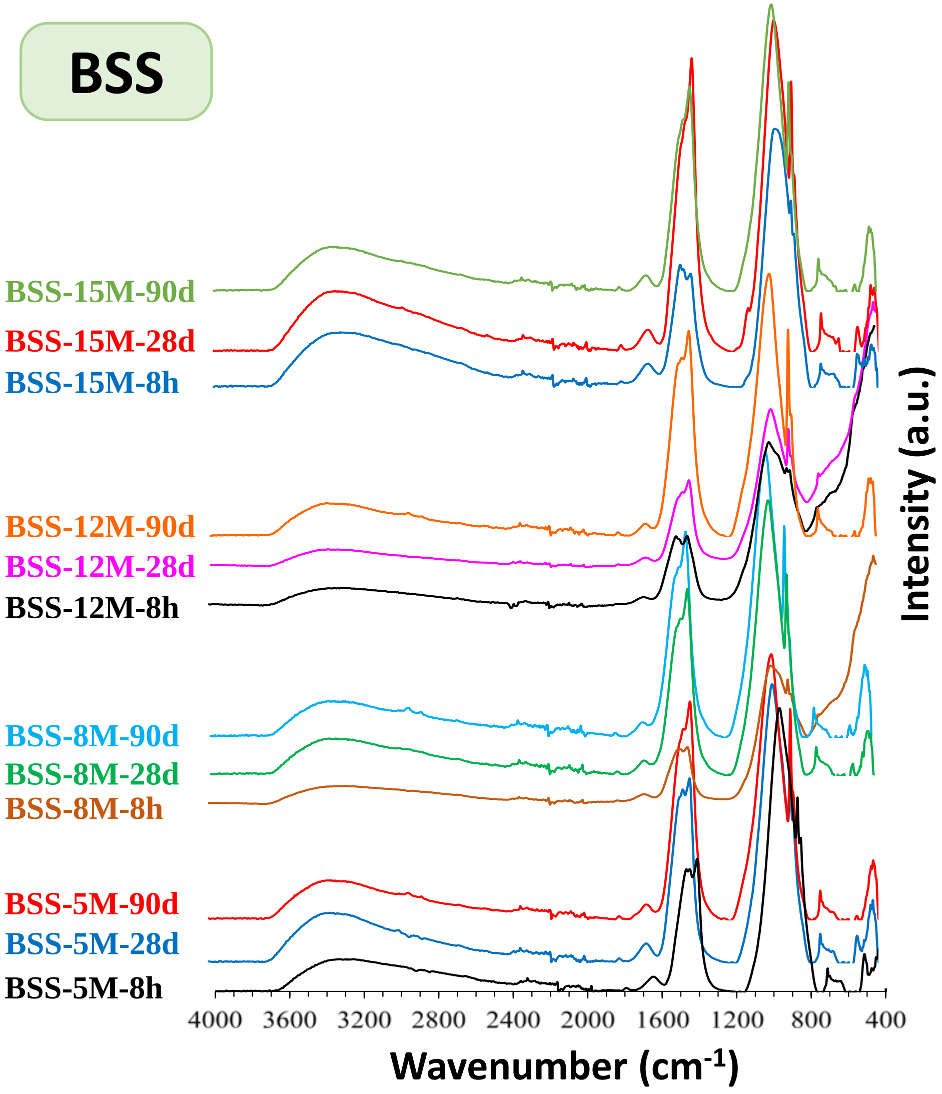
## Fourier Transform Infrared Spectroscopy (FTIR)

**BSS**

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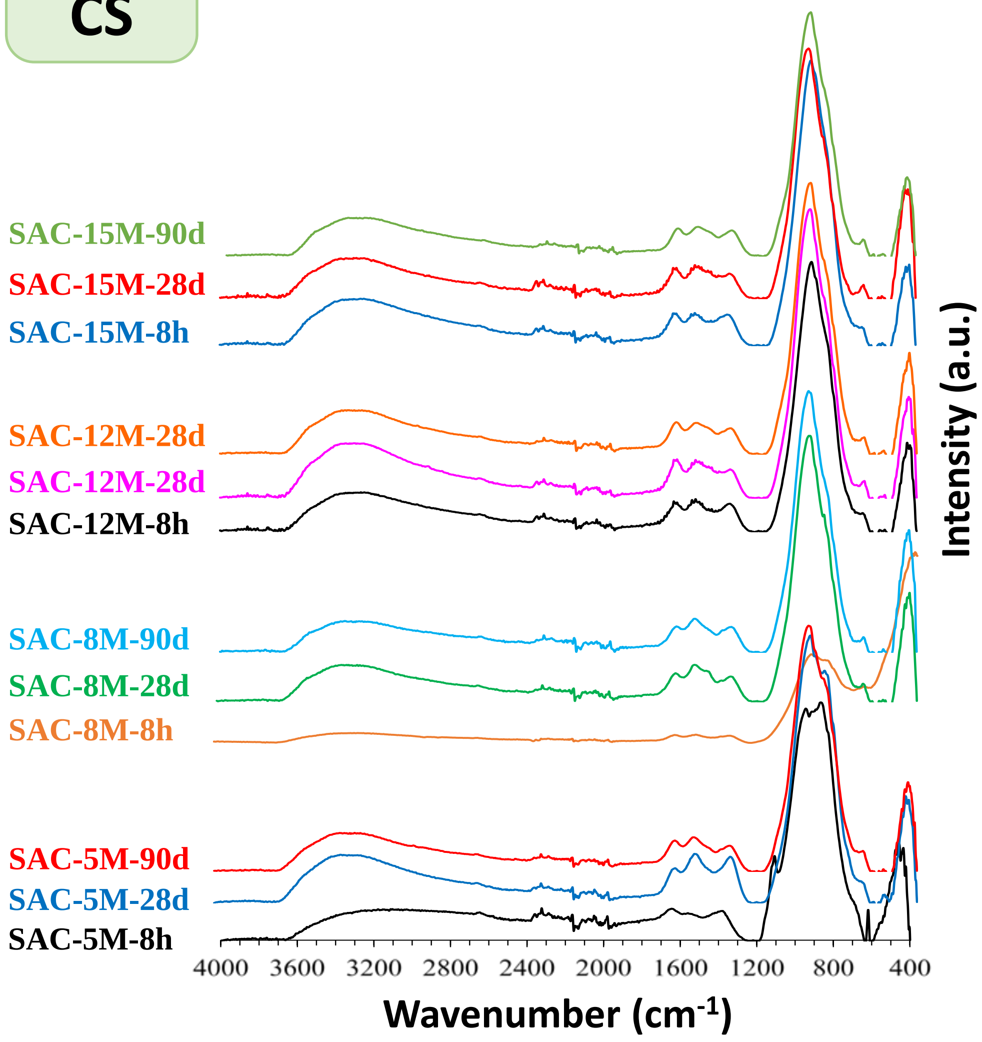
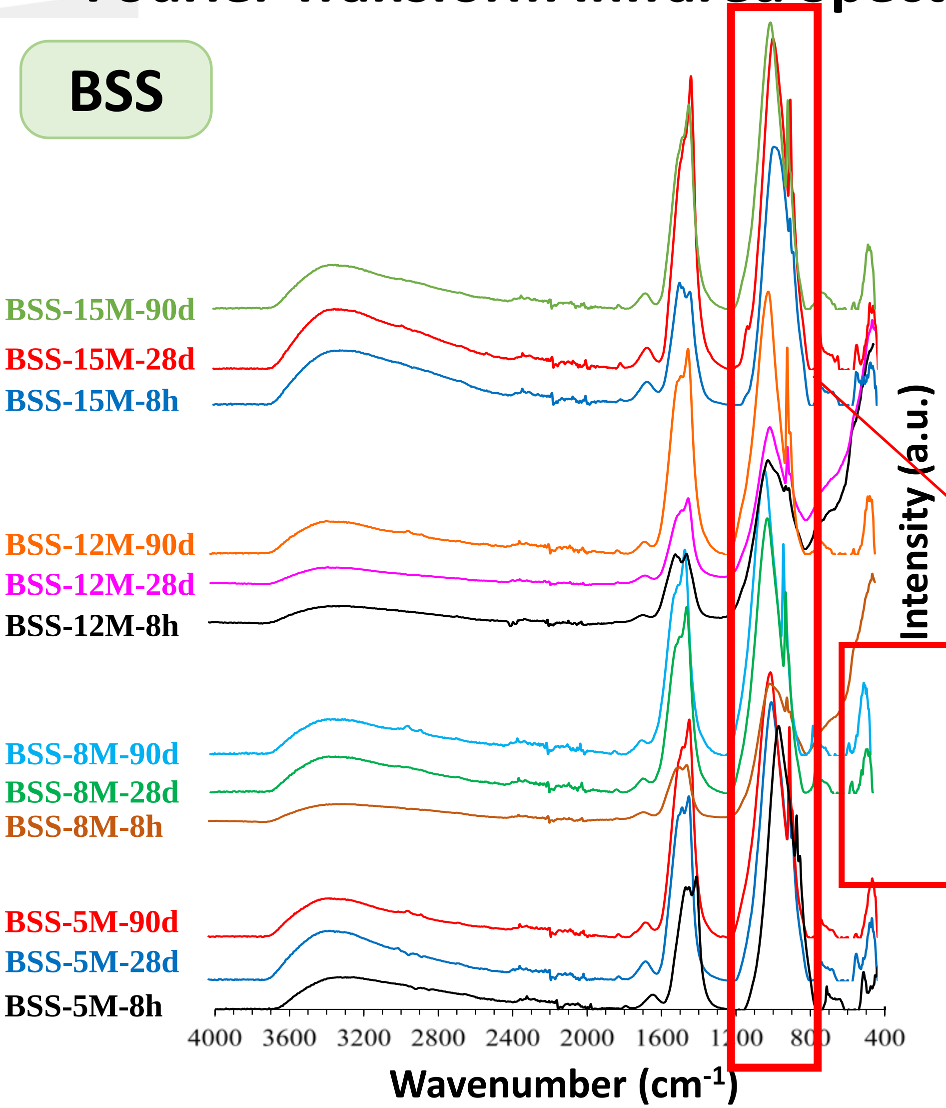


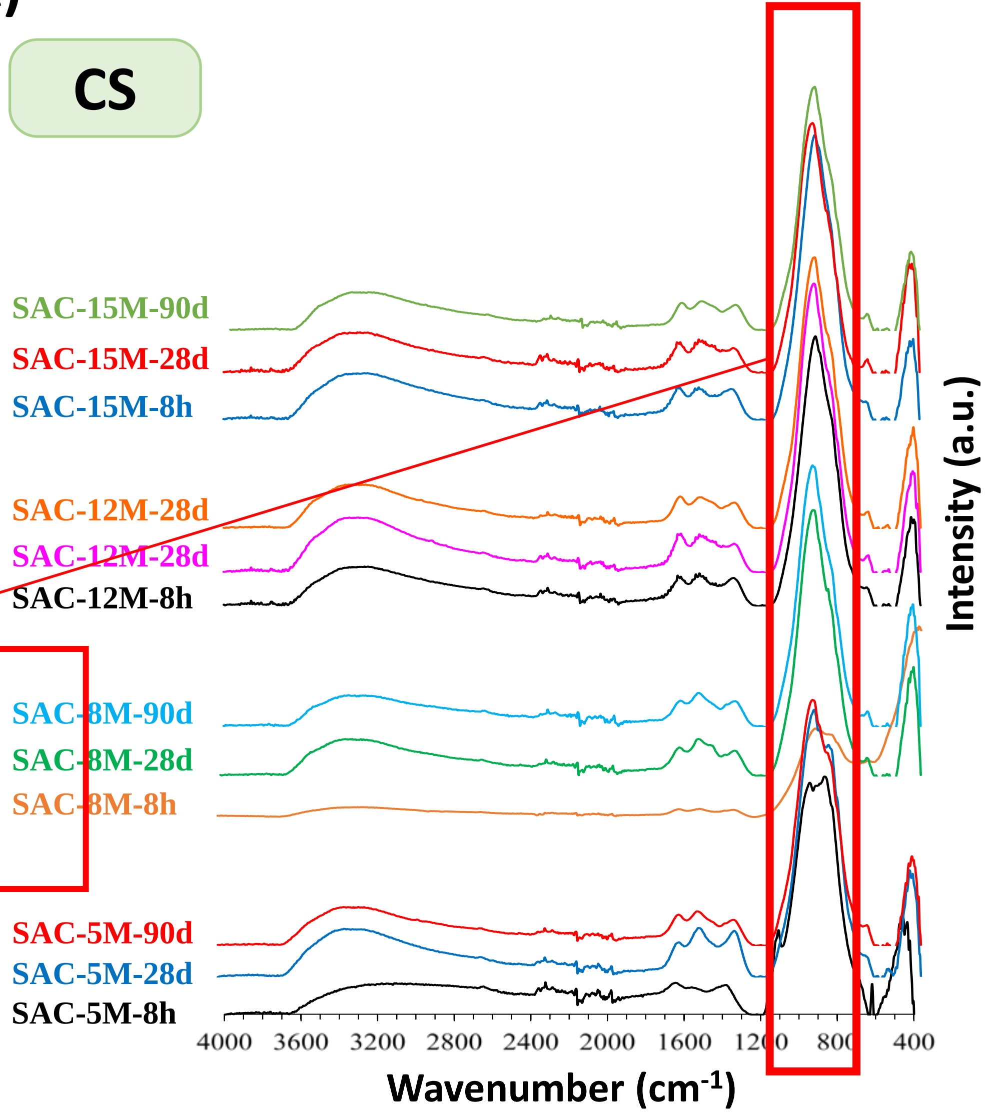
# RESULTS AND DISCUSSION

## Fourier Transform Infrared Spectroscopy (FTIR)




Band centred at 962-945 $cm^{-1}$:

Si-O-T bonds (T is Si or Al)

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# RESULTS AND DISCUSSION

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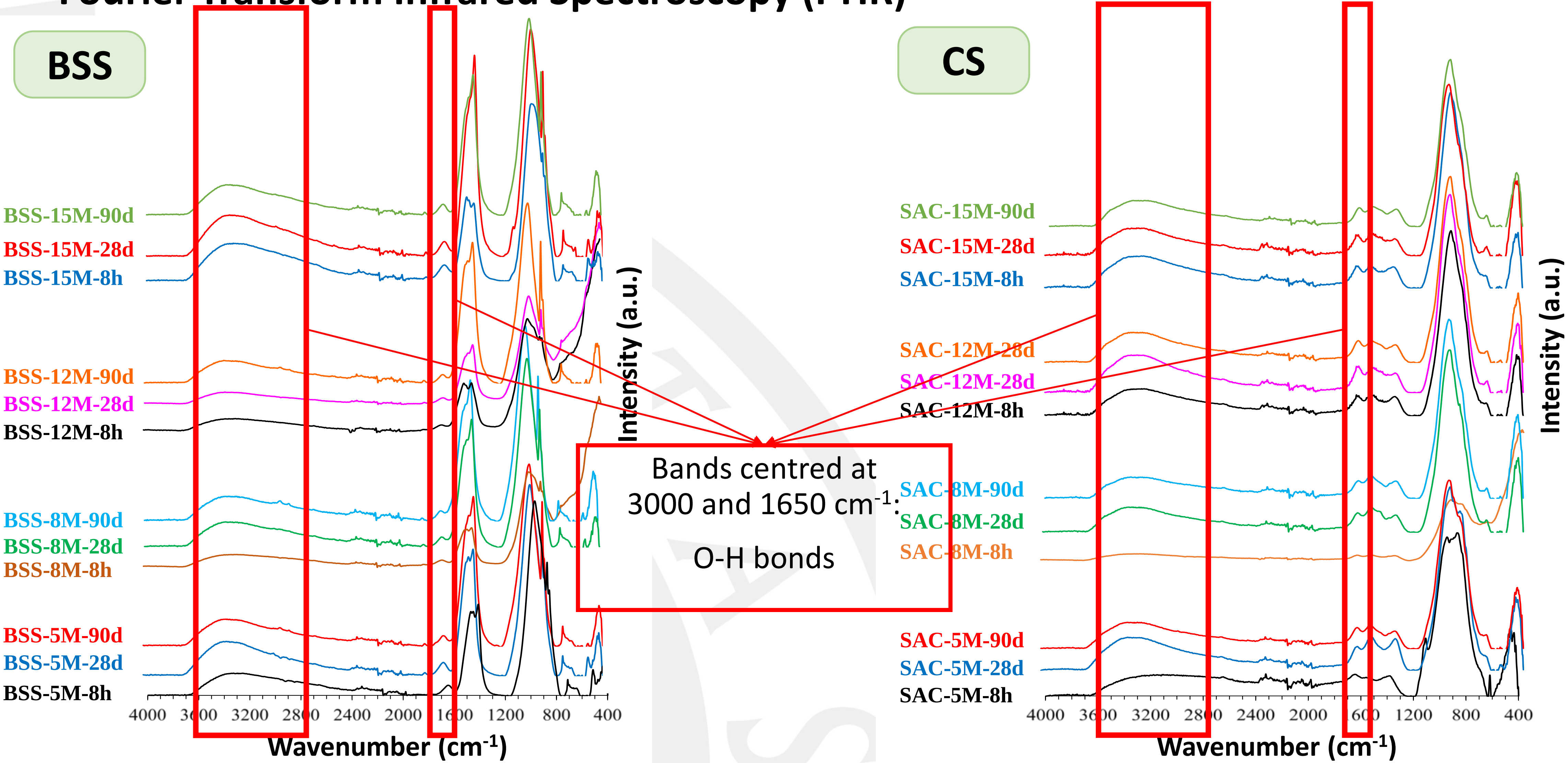
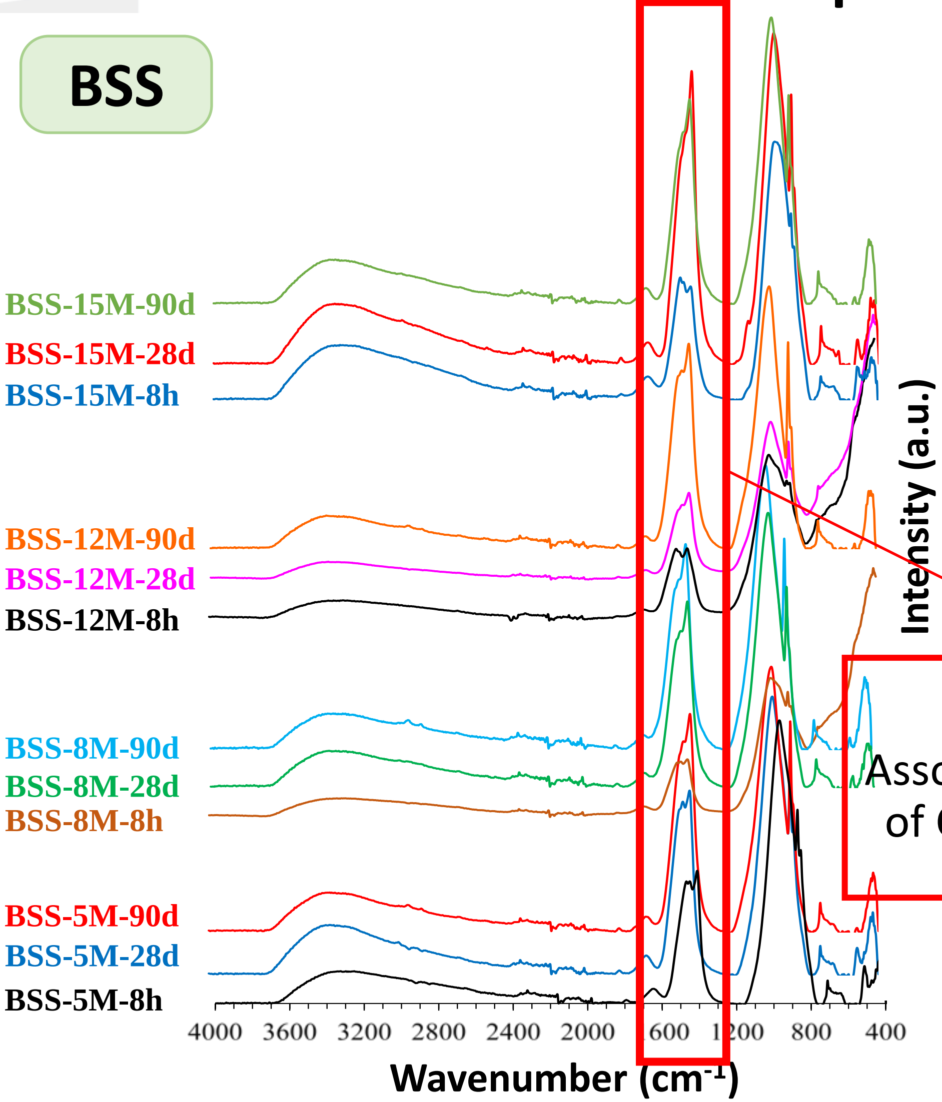
## Fourier Transform Infrared Spectroscopy (FTIR)

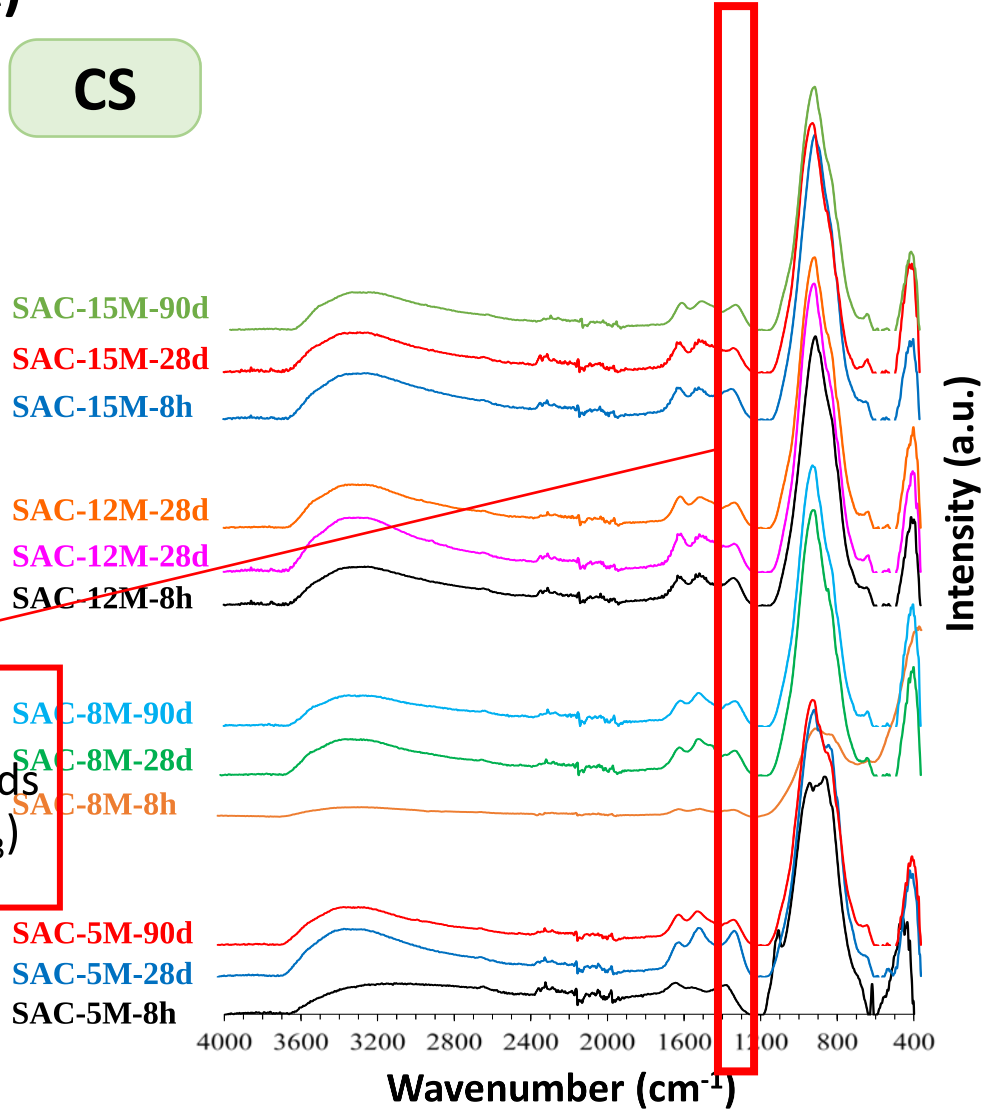


# RESULTS AND DISCUSSION



## Fourier Transform Infrared Spectroscopy (FTIR)




1442 $cm^{-1}$:

Associated to C-O bonds of Carbonates ($CaCO_3$)

# RESULTS AND DISCUSSION

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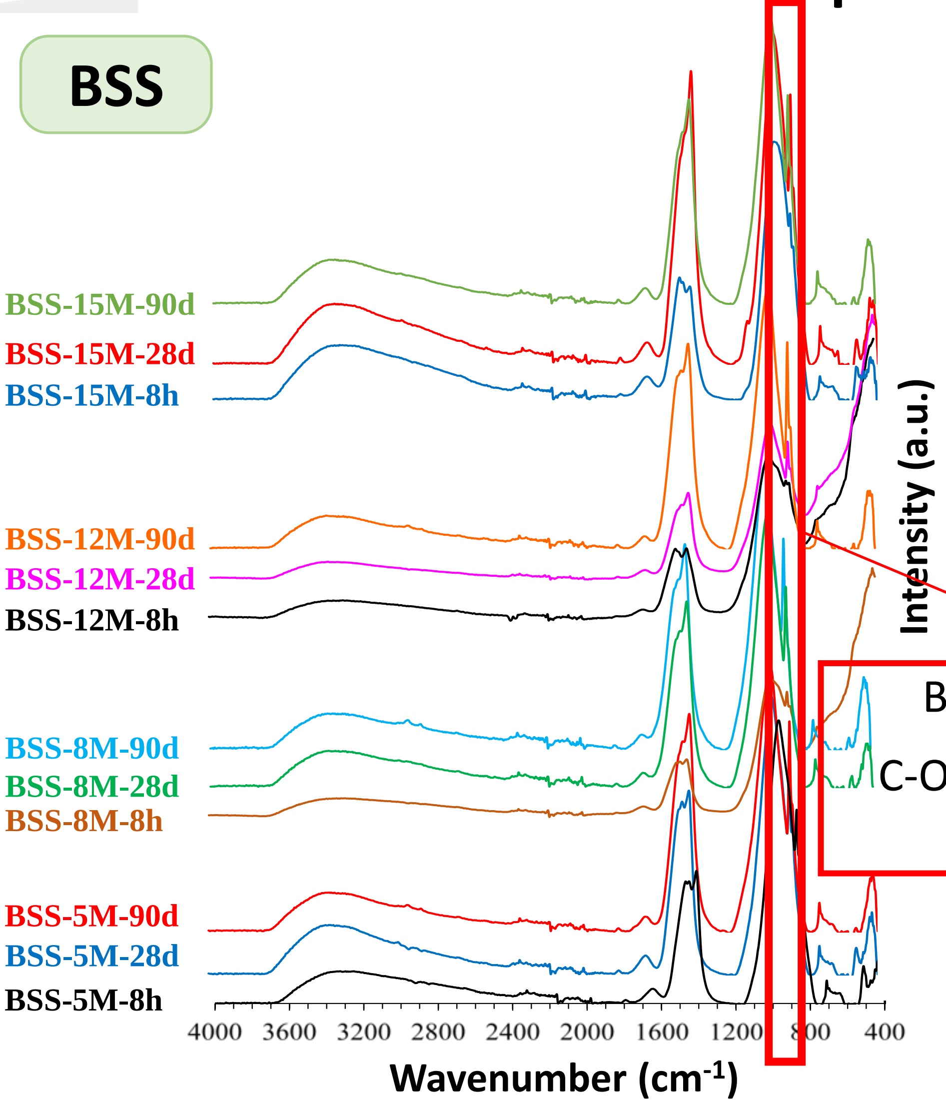
## Fourier Transform Infrared Spectroscopy (FTIR)

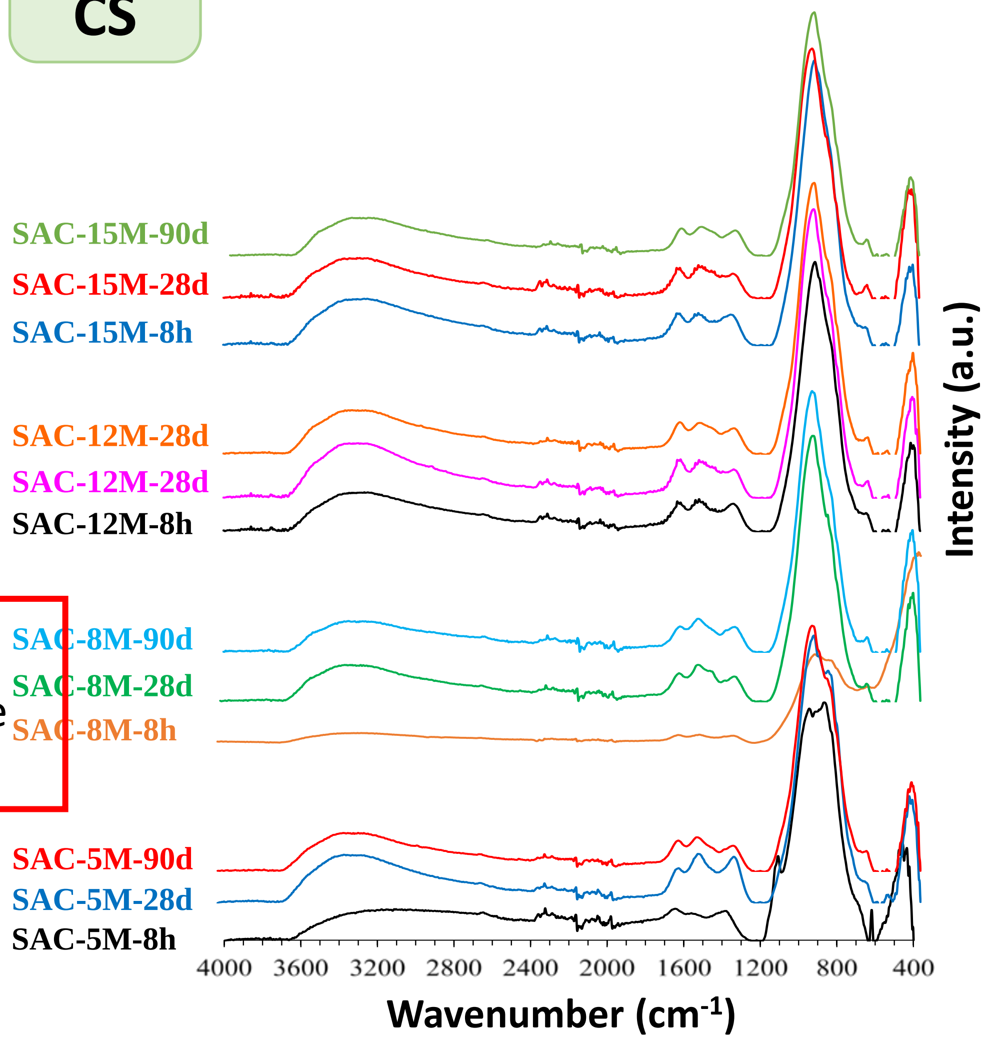
**BSS**




Band in 875 $cm^{-1}$:

C-O-C bond or Si-O-Fe bond

**CS**



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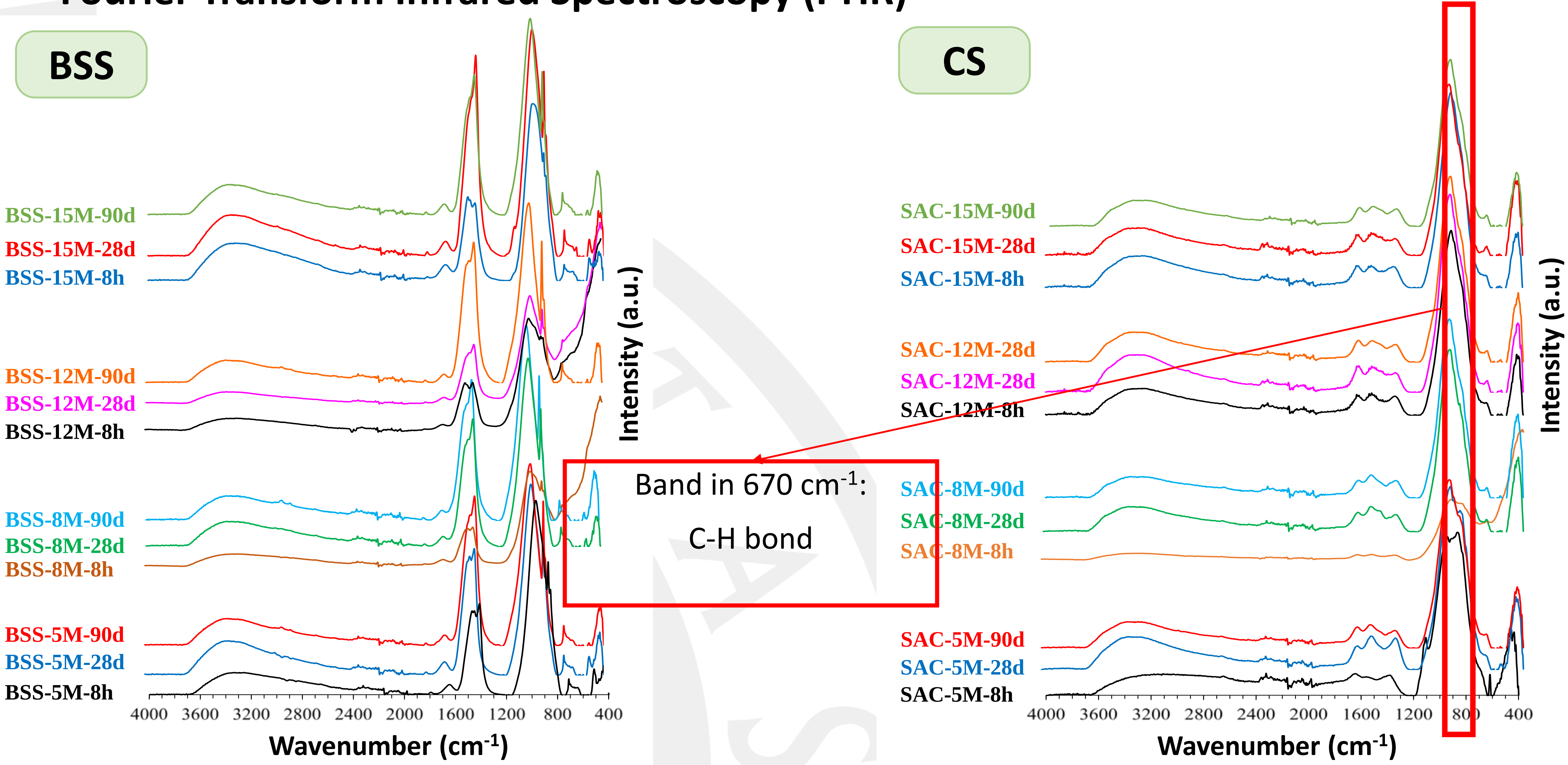
# RESULTS AND DISCUSSION

## Fourier Transform Infrared Spectroscopy (FTIR)



# RESULTS AND DISCUSSION

## XRD

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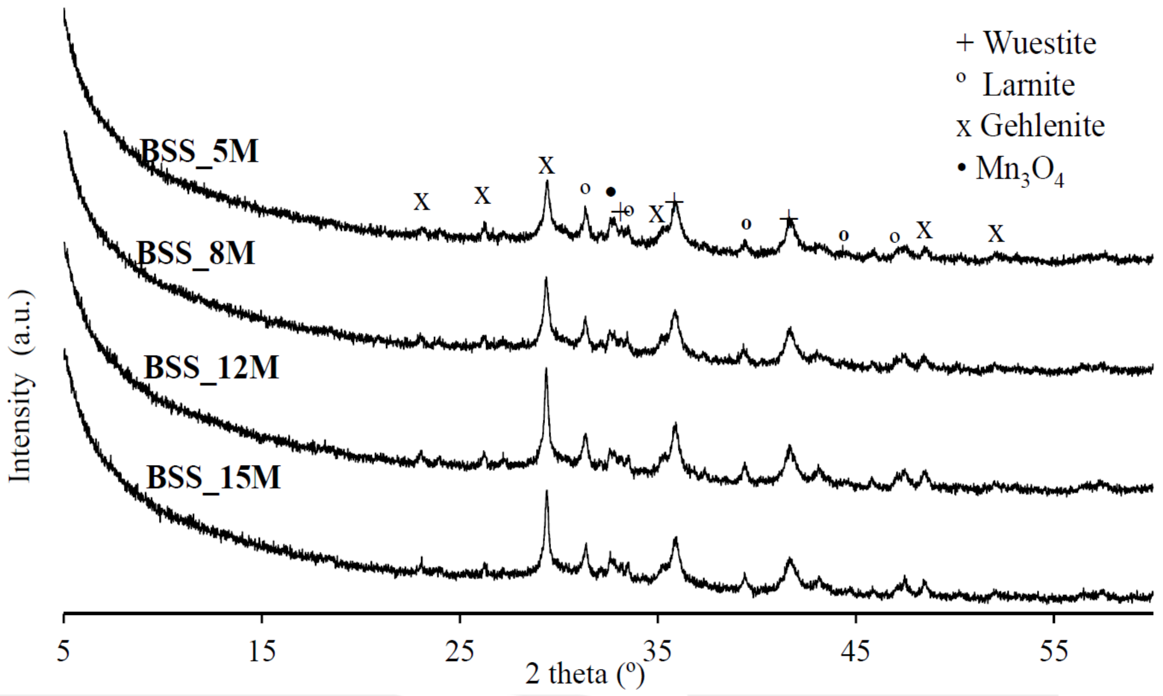
**BSS**

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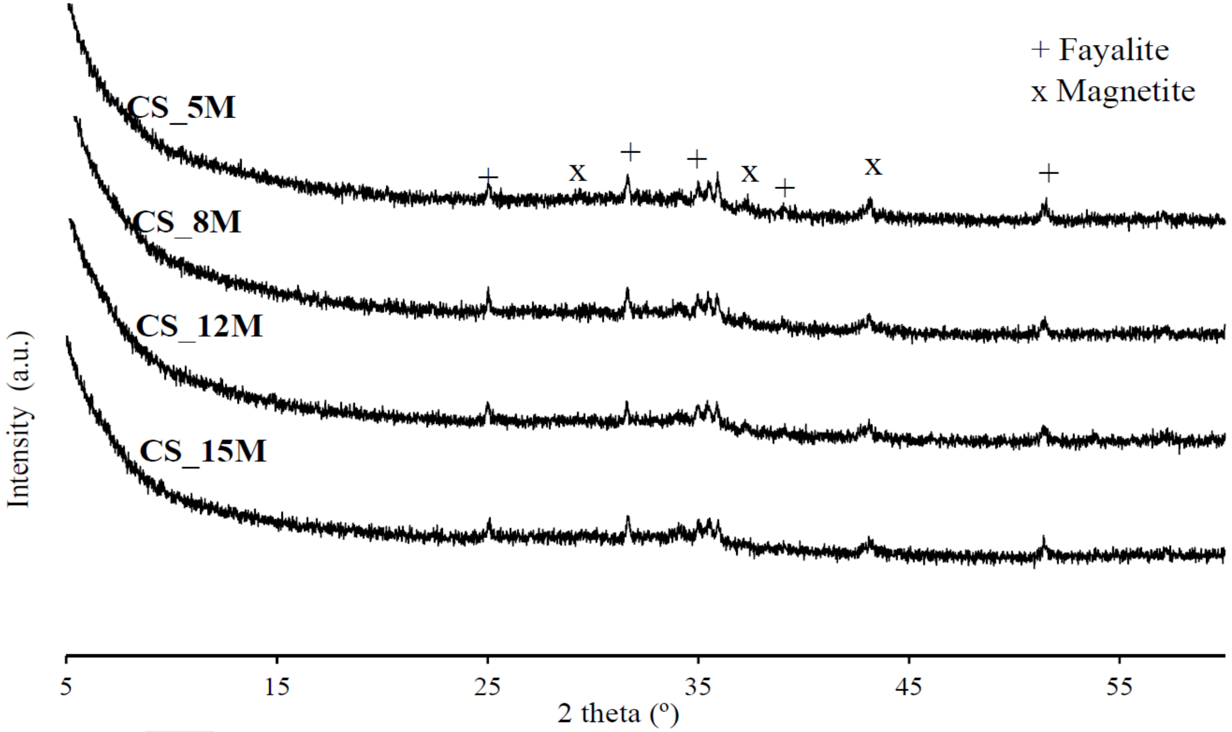

# RESULTS AND DISCUSSION

## XRD

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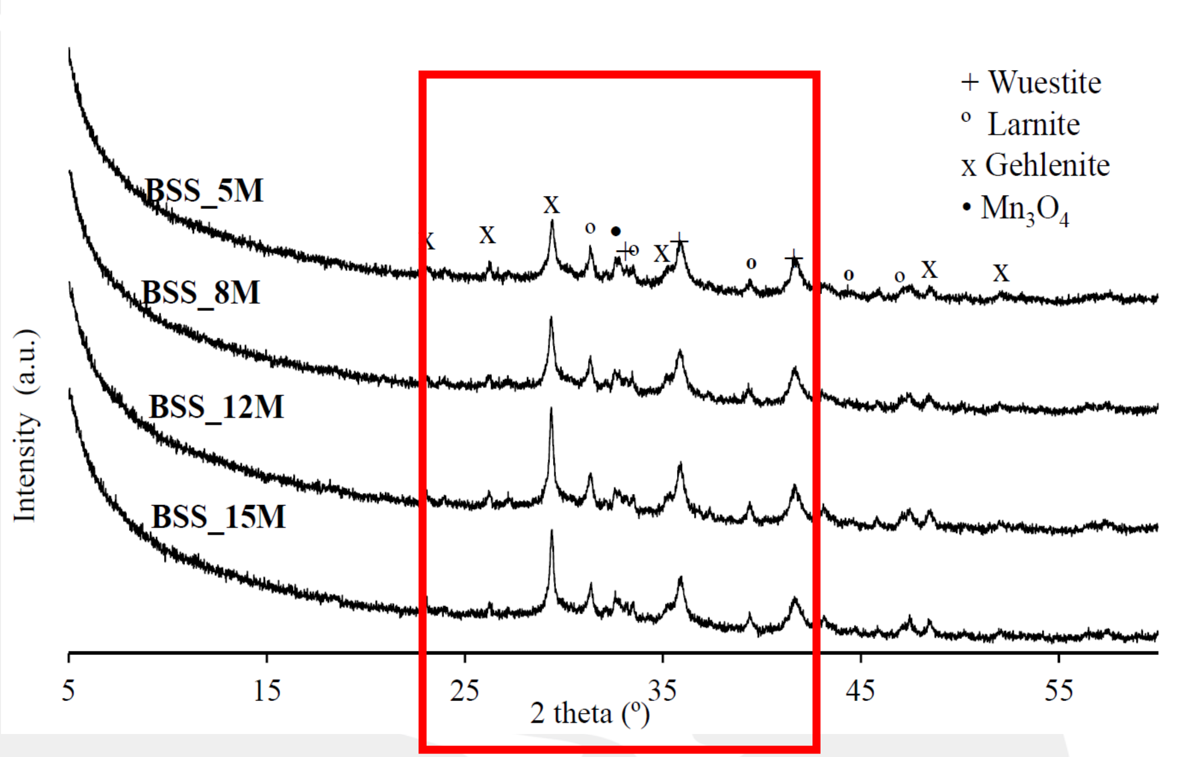


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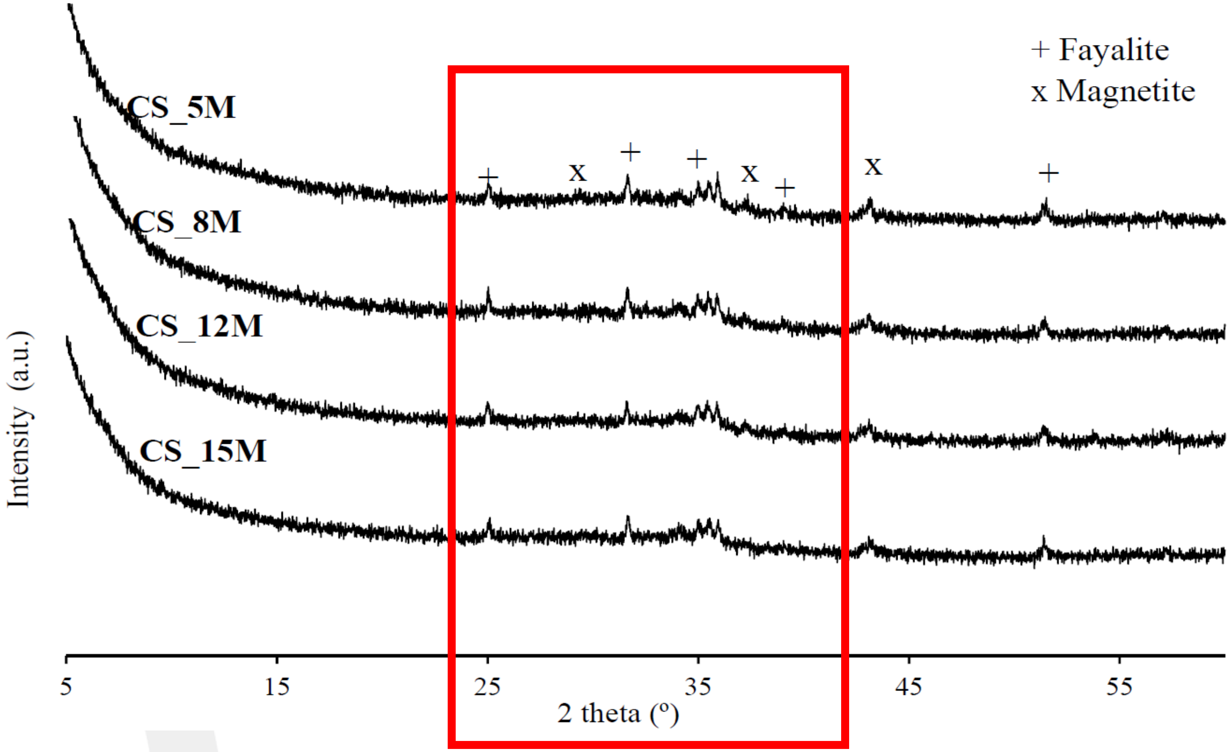

# RESULTS AND DISCUSSION

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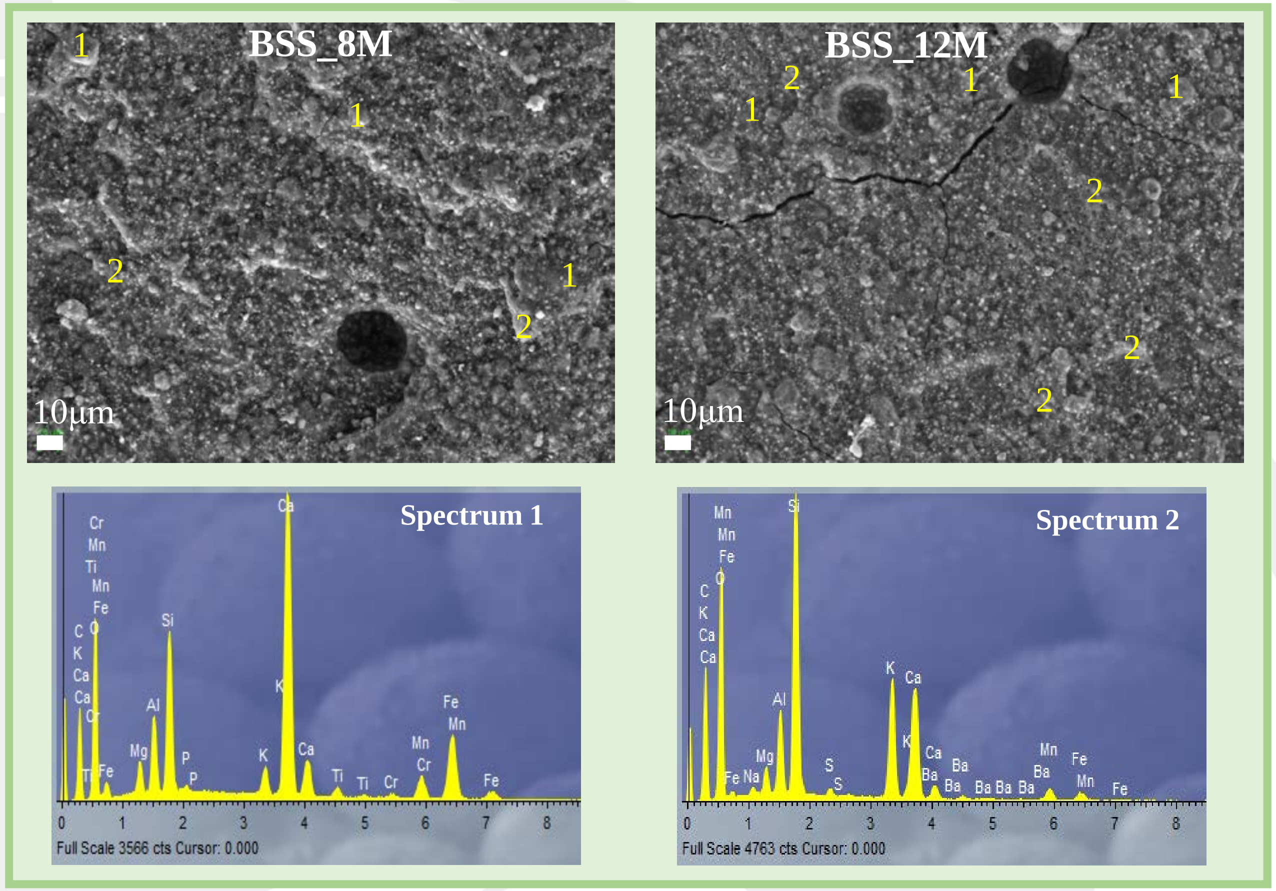
## SEM-EDX

**BSS**

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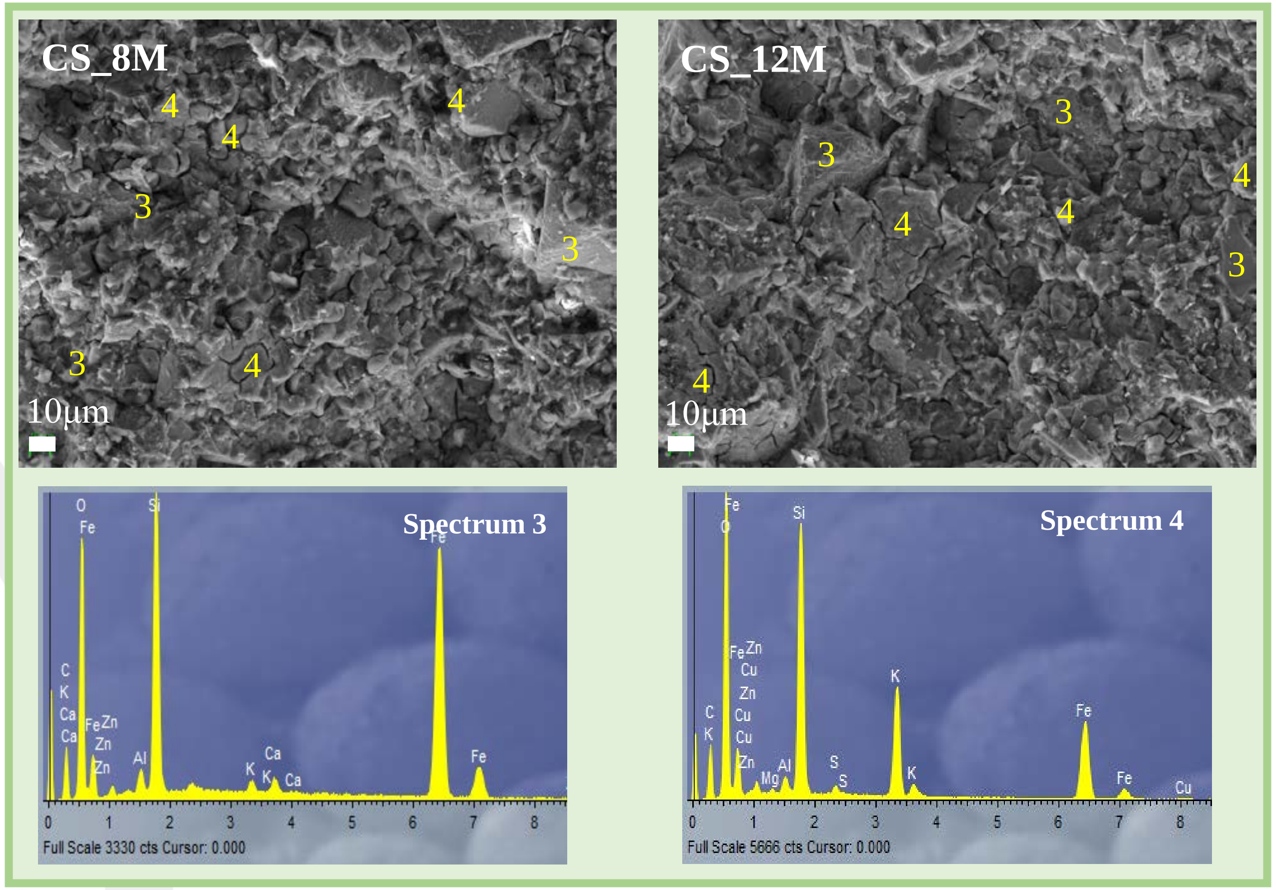

# RESULTS AND DISCUSSION

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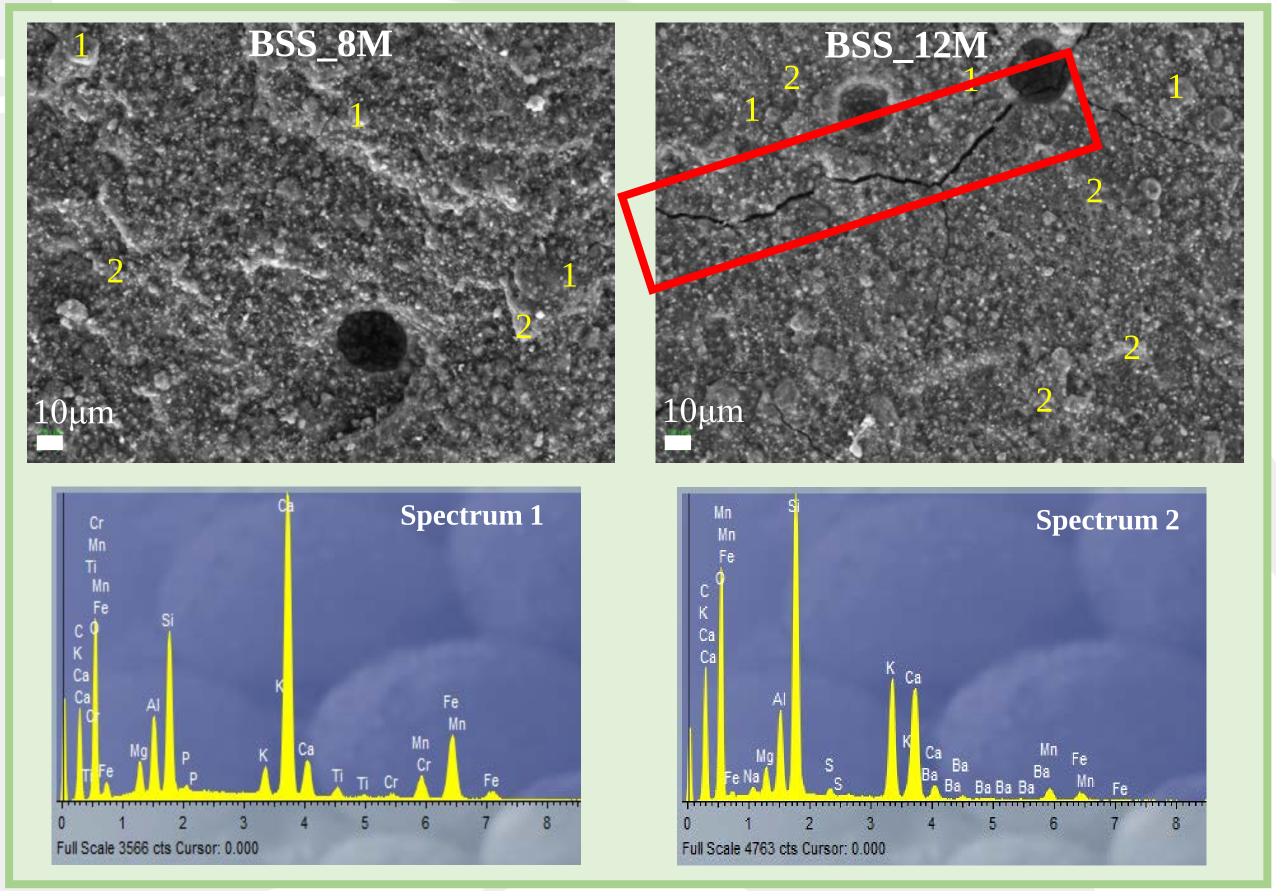


- C-A-S-H gel predominate
- Microcrash: high molar ratio
- Porous appear when molar ratio is increased.

# RESULTS AND DISCUSSION

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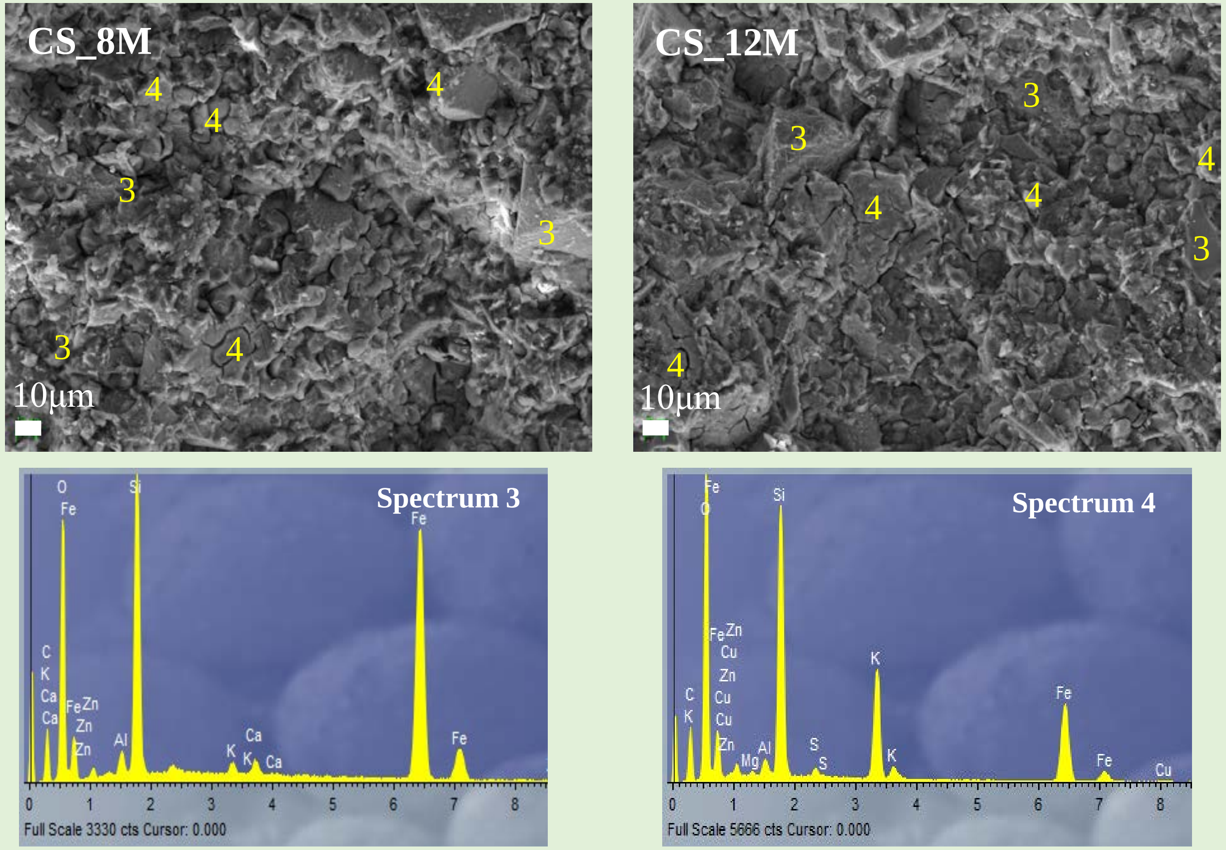
## SEM-EDX

**CS**




- K-A-S-H gel formed
- Less porous present in the matrix
- Less molar concentration used, more unreacted particles were found, obtaining a lower strength structure.

# CONCLUSIONS



- Two different materials were obtained: alkali-activated cement with BSS (C-A-S-H gel and in lower amount geopolymeric K-A-S-H gel) and geopolymers with CS (K-S-H gel).

- The highest strength at 90 days was performed by CS with any molar concentration of KOH. The reason could be higher amount of silica and lower $(FeO+CaO)/SiO_2$ molar ratio.

- Optimal activator different for each precursor:
  - BSS: best activator was using 35% 8M KOH and 65% Silicate.
  - CS found best activator with 35% 12M KOH and 65% Silicate.

- CS performed better physical properties than BSS, although real density of raw materials are close.

- Both precursors could be used as alternative material to Portland cement. Valuing these wastes could reduce greenhouse gases emission and avoid their disposal in landfills. Although better approach could be performed with CS, due to the development of high resistances.

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# THANK YOU

**ACKNOWLEDGEMENTS:**

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**M.A. Gómez-Casero, L. Pérez-Villarejo, P.J. Sánchez-Soto, D. Eliche-Quesada**

***Department of Chemical, Environmental, and Materials Engineering, Higher Polytechnic School of Jaén, University of Jaén, Campus Las Lagunillas s/n, 23071 Jaén, Spain***

***email: mgomez@ujaen.es***

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