APPLICATION OF STAINLESS STEEL SLAG WASTE AS A PARTIAL REPLACEMENT TO MANUFACTURE CEMENT MORTARS

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**INTRODUCTION**

**STAINLESS STEEL PRODUCTION**

- **2014**
  - 1st ASIA (71%)
  - 2nd EUROPE (21%)
  - 3rd AMERICA (8%)

- **Spain** 3rd European producer

- **2013**
  - World Steel Association, 2013

- **2014**
  - International Stainless Steel Forum, 2014
INTRODUCTION

STAINLESS STEEL MANUFACTURING PROCESS

Raw materials → Melting → Refining AOD → Refining VOD → Ladle Refining LF → Continuous casting

Surface grinding → Grinded slab

20% Raw Materials

WASTE

85% Waste

LANDFILL

AGGREGATES

SLAG

VALORISATION
VALORIZATION OF STAINLESS STEEL WASTE

AGGREGATES
- Road base
- Concrete
- Addition to Clinker

AGRICULTURE
- Soil improvement

CONSTRUCTION
- Concrete
- Addition to Clinker

AGRICULTURE
- Soil improvement

TREATING WASTEWATER

CONSTRUCTION
- Soil-cement
- Concrete
- CEMENT MORTAR

WASTE UTILIZATION

LESS USE OF NATURAL RESOURCES

SUSTAINABILITY
STAINLESS STEEL SLAG WASTE (SW) AS CEMENT REPLACEMENT IN MORTAR

OBJECTIVES

Few research related to stainless steel slag waste for use as a substitute for cement

Principal objective: study of cement replacement by different percentages of stainless steel slags crushed and without crushed for making mortars to determine the optimal replacement rate to increase the economic value of stainless steel slag waste and decrease the cement content

TREATMENT AND PROCESSING OF SW

- Study the cementitious properties
- Analysis of environmental effects through leaching test
- Study the effect on the compressive strength, flexural and shrinkage
- Application of multivariate analysis methods
STAINLESS STEEL SLAG WASTE AS CEMENT REPLACEMENT IN MORTAR

RESEARCH DESIGN

STAINLESS STEEL FACTORY ACERINOX

SW

PROCESSING

Unprocessed

Crushed - Sieved

REPLACEMENT

10%CEM
20%CEM
30%CEM

MANUFACTURE OF MORTAR

COMPRESSIVE STRENGTH
FLEXURAL STRENGTH
SHRINKAGE
MULTIVARIATE ANALYSIS

OXIDE COMPOSITION
LEACHING
STAINLESS STEEL SLAG WASTE AS CEMENT REPLACEMENT IN MORTAR

**CHEMICAL ANALYSIS**

- X-ray fluorescence (XRF) *(UNE-EN 196-2)*
- Leaching test *(UNE-EN 12457-3)*

**MECHANICAL ANALYSIS**

- Compressive Strength 1-7-28-90 DAYS *(UNE-EN 196-1)*
- Flexural Strength 1-7-28-90 DAYS *(UNE-EN 196-1)*
- Shrinkage 1-7-14-28-56-90 DAYS *(UNE-83831)*

**MATERIALS AND EXPERIMENTAL METHODS**

- SW Replacement 10% 20% 30%
- SW-C Replacement 10% 20% 30%
- Control

Standardized Sand + Water
### X-RAY FLUORESCENCE (XRF)

### CEMENTITIOUS PROPERTIES SW AND SW-C

<table>
<thead>
<tr>
<th></th>
<th>SiO$_2$ (%)</th>
<th>Al$_2$O$_3$ (%)</th>
<th>Fe$_2$O$_3$ (%)</th>
<th>CaO (%)</th>
<th>MgO (%)</th>
<th>SO$_3$ (%)</th>
<th>K$_2$O (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SW</strong></td>
<td>31,34</td>
<td>5,18</td>
<td>1,25</td>
<td>46,26</td>
<td>10,90</td>
<td>0,37</td>
<td>0,00</td>
</tr>
<tr>
<td><strong>SW-C</strong></td>
<td>30,31</td>
<td>5,01</td>
<td>0,93</td>
<td>46,45</td>
<td>11,51</td>
<td>0,36</td>
<td>0,00</td>
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</table>

**Chemical composition limits pozzolanic materials**
(Calleja, J. 1985)

**Chemical composition similar**
- CLINKER
- CONVENTIONAL FLY ASH

**Pozzolanic reaction characteristics**
LEACHING TEST
HEAVY METALS LEACHATE BY SW AND SW-C

CHEMICAL PROPERTIES
RESULTS

Classification
L/S=2
SW Non hazardous
SW-C Non hazardous
L/S=10
SW Non hazardous
SW-C Non hazardous

NON HAZARDOUS

Stainless steel slag
L/S = 2 l/kg

Stainless steel slag
L/S = 10 l/kg

Concentrations in the leachate (mg/kg)

HAZARDOUS
NON-HAZARDOUS
INERT

Sw
Sw-C
RESULTS

COMPRESSIVE STRENGTH
STAINLESS STEEL SLAG WASTE AS CEMENT REPLACEMENT IN MORTAR

LOSS OF COMPRESSIVE STRENGTH LOWER 25%
REPLACEMENT 10% Sw AND Sw-C COMPRESSIVE STRENGTH INCREASES
SW-C BETTER RESULTS

Compressive strength (Mpa)
28 DAYS

CONTROL S1 S2 S3

S1 10% REPLACEMENT
S2 20% REPLACEMENT
S3 30% REPLACEMENT

MECHANICAL BEHAVIOR

RESULTS
FLEXURAL STRENGTH
STAINLESS STEEL SLAG WASTE AS CEMENT REPLACEMENT IN MORTAR

MECHANICAL BEHAVIOR
RESULTS

LOSS OF FLEXURAL STRENGTH LOWER 15%

REPLACEMENT 10% Sw AND Sw-C FLEXURAL STRENGTH INCREASES

FLEXURAL STRENGTH VS COMPRESIVE STRENGTH

HIGH POSITIVE CORRELATION AMONG THE COMPRESSIVE STRENGTH AND FLEXURAL STRENGTH

\[ y = 0.1391x + 3.9232 \]
\[ R^2 = 0.9455 \]
SHRINKAGE
STAINLESS STEEL SLAG WASTE AS CEMENT REPLACEMENT IN MORTAR

RESULTS

REPLACEMENT 10% Sw AND Sw-C PRESENT VALUES OF RETRACTION SIMILAR THAT THE CONTROL

THE MORTARS WITH A REPLACEMENT OF 20% AND 30% Sw AND Sw-C HAVE HIGH SHRINKAGE VALUES
The mechanical behavior of mortars must be analyzed as a whole (Compressive Strength, Flexural Strength and Shrinkage).

Multivariate analysis: a useful tool to evaluate the influence of addition of slag waste in the mechanical behavior.

**MULTIVARIATE ANALYSIS METHODS**

- **Ordination Analysis.** Principal Components Analysis (PCA)
- **Multivariate Analysis of Variance (MANOVAs)**
### RESULTS

#### MANOVAs

<table>
<thead>
<tr>
<th>Treatment Comparison</th>
<th>Pillai</th>
<th>approx F</th>
<th>Pr(&gt;F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical behavior vs All treatment</td>
<td>1.86</td>
<td>9.53</td>
<td>&lt;0.0001</td>
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</table>

**DIFFERENT**

#### Control vs Replacement Series

<table>
<thead>
<tr>
<th>Control vs</th>
<th>Pillai</th>
<th>approx F</th>
<th>Pr(&gt;F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control vs S1</td>
<td>0.6775</td>
<td>23.11</td>
<td>&lt;0.0001</td>
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<tr>
<td>Control vs S2</td>
<td>0.6279</td>
<td>18.56</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Control vs S3</td>
<td>0.9691</td>
<td>345.75</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

**DIFFERENT**

#### Unprocessed vs Crushed

<table>
<thead>
<tr>
<th>Unprocessed vs</th>
<th>Pillai</th>
<th>approx F</th>
<th>Pr(&gt;F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW vs SW-C</td>
<td>0.7037</td>
<td>26.12</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>S2SW vs S2SW-C</td>
<td>0.1827</td>
<td>2.46</td>
<td>0.08</td>
</tr>
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</table>
The cement replacement by stainless steel slag waste provides an increased in compressive and flexural strength for 10% substitution respect to the control. For stainless steel slag waste crushed we are observed better results. For mortars manufactured with this percentage, the retractions are similar to the control mortar.
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THANKS FOR YOUR ATTENTION