

X JORNADAS CÁTEDRA ACERINOX
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CONSTRUCCIÓN DE CARRETERAS CON ESCORIAS DE ACERO INOXIDABLE

UN NOVEDOSO AGLOMERANTE PARA CAPAS DE CARRETERA

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¿ ES POSIBLE CONSTRUIR CARRETERAS CON **ESCORIAS** **DE ACERO INOXIDABLE?**



Carreteras - Estabilización de suelos y caminos rurales



Estabilización base de carreteras

Estabilización de suelos

Carreteras - Estabilización de suelos y caminos rurales



Modificaciones a corto plazo de las propiedades geotécnicas

Modificaciones a largo plazo de las propiedades del suelo

HRB

Clinker

Escoria granulada de horno alto

Puzolana natural

Cal

Ceniza volante

Caliza

1 tonelada Cada tonelada de cemento libera 1.000kg de CO₂

1. Producción de cemento: Piedra caliza y arcilla se muelen y se mezclan con mineral de hierro o ceniza

2. Piroprocesamiento: Las materias primas se calientan en un horno rotatorio a 1.450 grados C. La temperatura alta causa una reacción química que libera enormes cantidades de CO₂

3. Calcinación: La piedra caliza (CaCO₃) más el calor producen cal (CaO) y CO₂

4. Clinker: Los aluminosilicatos de la arcilla forman minerales con la cal – silicatos de calcio, aluminatos y ferroaluminatos – que producen clinker de cemento

Características no adecuadas a largo plazo

- Resistencia mecánica insuficiente.** En suelos arcillosos plásticos, a largo plazo el tratamiento solo con cal puede ser insuficiente, siendo necesaria doble estabilización cal-cemento.
- Presencia de materia orgánica o sales.** Provoca la detención de formación de compuestos cementantes y puede producir reacciones expansivas debido a la formación de ettringita.
- Alto contenido en carbonato cálcico.** La reacción de estabilización a largo plazo puede ser reversible. El suelo puede perder las mejoras obtenidas y sus propiedades resistentes , volviéndose a formar materiales con alta plasticidad y expansivos.

¿Por que utilizar EAI?

EAI



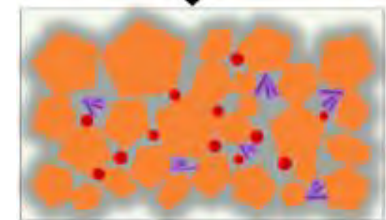
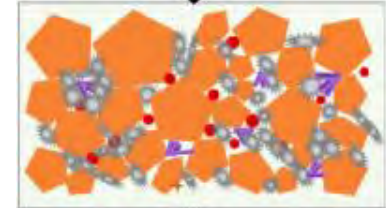
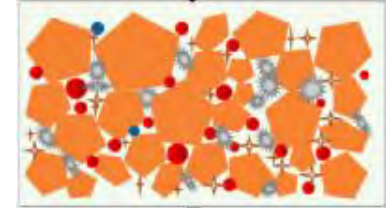
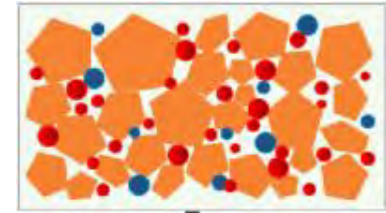
Formación
Silicato cálcico (CSH)
Hidratos de aluminato cálcico (CAH)



**REACCIÓN
PUZOLÁNICA**



**MEJORA DE PROPIEDADES
MECÁNICAS**



¿Por que utilizar EAI?



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Effect of stainless steel slag waste as a replacement for cement in mortars. Mechanical and statistical study

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HIGHLIGHTS

- Different treatments of stainless steel slag waste (SW) were performed to improve it.
- Chemical properties of SW showed a positive cementitious capacity.
- SW processed showed an increase in mechanical strength results.
- SW processed through simple treatments can be used as a substitute for cement.

GRAPHICAL ABSTRACT

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Cement substitute
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ABSTRACT

This document studies replacing cement by stainless steel slag waste and improving the mechanical properties of the slag waste by using different types of treatments. The application of stainless steel slag waste reduces the use of raw materials for manufacturing cement and provides a profit from the large amount of waste generated. This study analyzes the cementation and pozzolanic reaction characteristics of stainless steel slag waste to evaluate its strength activity index and its environmental impact. The cement was replaced with different substitution percentages of untreated stainless steel slag waste and slag waste that was processed through crushing, burning and both treatment to determine the optimum replacement ratio according to its mechanical properties. A study based on multivariate factor analysis was developed to compare these processed wastes according to their mechanical behaviour. The decision mechanism consists of a feature extraction method to evaluate the wastes used as a cement substitute.

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1. Introduction

Stainless steel production is currently one of the most dynamic sectors of the manufacturing industry due to a large increase of the use of this product in the construction and industrial sectors; considerable amounts of waste are generated from these factories [1,2]. These high amount of waste generated is not only a quantity crisis but also an environmental problem [3–6]. For every three tons of stainless steel produced, approximately one ton of slag waste is generated [1]. Steel slag is a by-product of the steelmaking and steel refining processes. Different types of steel slag are generated from basic-oxygen-furnace (BOF) steelmaking, electric-arc-furnace (EAF)

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- Valorización EAI
- Capacidad cementante



ESCORINOX 1
2017

¿Por que utilizar EAI?

materials **MDPI**

Article
Potential of Stainless Steel Slag Waste in Manufacturing Self-Compacting Concrete

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Abstract: The volume of slag generated from the steel industry is a source of growth resources which is constantly increasing, specifically in the production of stainless steel. Specific and unique slag with unique characteristics are obtained, which allow considering an approach aimed at their use in new recycling uses. This work shows the benefits of using stainless steel slag as a substitute for limestone filler in the manufacture of self-compacting concrete. The influence of different treatments applied to slag on physical and chemical properties was studied. On the other hand, the mechanical behaviour as well as the durability against self-compacting concrete, has been analysed. Very encouraging results were obtained, since this research demonstrates the possible application of this stainless steel slag as a construction material improving sustainability and preventing circular economy processes, which are achieved through the implementation of the 3R approach (3R) as a solution.

Keywords: stainless steel slag; treatment; self-compacting concrete; mechanical and durability properties

1. Introduction

In the industrial and economic sectors, it is increasingly essential to introduce sustainability both in the use of raw materials and raw materials and in production processes. The manufacture and production of steel constitute one of the most important industries in the world. Different raw materials, in their various industrial processes, involve the generation of different waste. The main waste generated in volume in the manufacturing processes of these materials is steel slag [1]. Steel dross and production in Europe, Asia, the Americas and China represent an increasing growth in 2018. Among the main drivers of steel demand in Europe are the construction and machinery engineering industries [2].

The steel production sector in India continues to lead. The stainless materials used in the manufacture of stainless steel are nickel, chromium, molybdenum and boron scrap.

World production of stainless steel in 2019 exceeded 16.7 million tonnes, an increase of 3.5% over the previous year's volume. The 90% of the world's leading stainless steel producers, China, grew by 5.1% to 16.7 million tonnes. The figure represents 42% of total production of stainless steel [3].

Despite the fact that stainless steel is a material that can be recycled over and over again, which makes it possible to achieve sustainable development and the circular economy, its production generates certain residues, stainless steel slag (SS) being the generated in greater volume (70%) [4].

We have studied chemical properties and microstructure to study the potential steel slag waste as blast furnace slag (BFS). This is composed mainly of calcium and silica oxides, and these chemical characteristics obtain promising properties [5]. Despite the promising potential that they may have for their application, there are few studies that research their use as a substitute for cement.

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materials **MDPI**

Article
Alkali-Activated Stainless Steel Slag as a Cementitious Material in the Manufacture of Self-Compacting Concrete

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Abstract: This work describes the characteristics of self-compacting concrete (SCC) with 50% cement substitute. As an alternative to reduce the volume of slag as a substitute for blast furnace slag (BFS) and to reduce the environmental impact of the steel industry, this research focuses on the use of stainless steel slag as a substitute for limestone filler in the manufacture of self-compacting concrete. The influence of different treatments applied to slag on physical and chemical properties was studied. On the other hand, the mechanical behaviour as well as the durability against self-compacting concrete, has been analysed. Very encouraging results were obtained, since this research demonstrates the possible application of this stainless steel slag as a construction material improving sustainability and preventing circular economy processes, which are achieved through the implementation of the 3R approach (3R) as a solution.

Keywords: stainless steel slag; alkaline-activated concrete; self-compacting concrete; mechanical and durability properties

1. Introduction

Advances in society to find new materials with better characteristics, more resistant to corrosion, and less pollution have been developing over time. Within these lines of research, for an increasing demand of finding substitute materials for the most used construction material, ordinary Portland cement (OPC), a long-term use is expected to be the construction material of the future. These characteristics mean that they can be converted into a partial or total substitute for cement.

Cement uses more water without adding the strength of alkaline-activated cementitious materials. These materials show different preparation and application, being an alternative to OPC, resulting in less use of natural resources, energy, and CO₂ emissions [1].

In recent years, great progress has been achieved in the manufacture of alkali-activated materials and products as well [2].

In addition, progress must be continuous to improve properties comparable to those of OPC. They are seen as an alternative to OPC, due to the lower emissions (up to 50% less of CO₂ in their manufacture [3]). Furthermore, they show improvements in the mechanical properties and the ability of the manufactured material [4] such as good resistance to freeze-thaw cycles and to the action of acids, low permeability [5], and easy adhesion to glass, organic materials, concrete, and steel.

For the improvement of knowledge and the development of new raw materials in the preparation of alkali-activated binders, as a substitute for OPC, several trials are starting to be carried out to produce a new generation and as follows [6]. Among these alternatives, some industrial waste products, which complement conventional cementitious materials, can be used to partially or completely substitute OPC in concrete production [6].

In the context of alkaline-activated binders, it has been demonstrated that the presence of silica is necessary. In recent years, research has been developed studies for the replacement of synthetic alkaline silicates with hydrogels or zeolites [7].

Among the main waste generated by a source of silica are what come from agricultural industries, e.g., rice husk ash, sugar cane waste ash, or furnace ash [8]. All these wastes have been studied by different researchers and it has been observed that they

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El objetivo de Acerinox es:

Reducir un 90% los residuos enviados a vertedero para 2030 tanto como referencia los datos de 2020

Best practices

Existen otros proyectos destinados a potenciar la economía circular.

- Programa Comfutoro:** Acerinox apoya a potenciar el talento de nuevos investigadores a través de la colaboración con la Fundación General CSIC (FGCSIC). Este programa está destinado a favorecer y promover el trabajo de jóvenes investigadores en un área de gran interés y preocupación como la economía circular. En concreto, Acerinox apoya el proyecto para el desarrollo y valorización de las escorias siderúrgicas cuyo objetivo es reutilizarlas como aditivos de materiales de construcción fotocatalíticos.
- Escorinox-2:** Proyecto financiado íntegramente por Acerinox con la Universidad de Córdoba. El proyecto Escorinox 2 consiste en el estudio de la aplicación de escorias de acero inoxidable como sustituto de cemento y relleno calzo en la fabricación de hormigones autocompactantes. Los resultados que se han obtenido muestran que el hormigón fabricado tiene un comportamiento mecánico similar a un hormigón autocompactante tradicional. El estudio ha demostrado que es posible fabricar hormigón autocompactante con una disminución de hasta el 50% de cemento, presentando únicamente una reducción del 14% de la resistencia a compresión, cumpliendo con los requisitos técnicos necesarios para su aplicación. El siguiente paso es avanzar en el proyecto Escorinox-3, hacia la aplicación a escala real.

ESCORINOX 2 2018

- Valorización EAI
- Capacidad cementante
- HAC con EAI
- Activación alcalina EAI

ESCORINOX 1 2017



¿Por que utilizar EAI?



- Valorización EAI
- Capacidad cementante

ESCORINOX 1
2017

ESCORINOX 2
2018

- HAC con EAI
- Activación alcalina EAI

- Hormigón con EAI
- Aplicación a escla real

ESCORINOX 3
2020

¿Por que utilizar EAI?



EAI



Reducción



HRB



Clinker



Escoria granulada de horno alto



Puzolana natural



Cal



Ceniza volante



Caliza



Sustitución



REDUCCIÓN HUELLA DE CARBONO



DISMINUCIÓN EXTRACCIÓN RECURSOS NATURALES



REUTILIZACIÓN DE RESIDUOS



MEJORA DE PROPIEDADES DEL SUELO

Nuevos conglomerantes hidráulicos – HRB-EAI



FASE 1

- Análisis de propiedades
- Selección EAI

FASE 2

- Tratamiento EAI
- Índice de Actividad Resistente

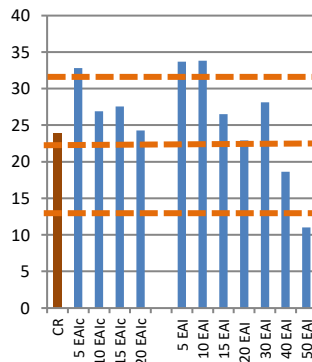
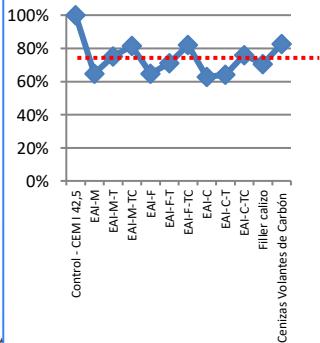
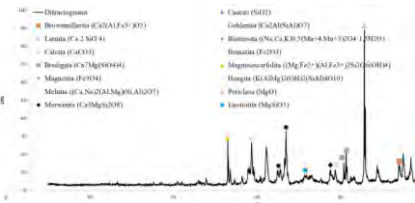
FASE 3

- Evaluación propiedades HRB-EAI

FASE 4

- Propiedades suelo estabilizado HRB-EAI

CONCLUSIONES Y APLICACIÓN



Nuevos conglomerantes hidráulicos – HRB-EAI



$SiO_2 - CaO - MgO - Al_2O_3$

Óxido de calcio reactivo (CaO) y de dióxido de silicio reactivo (SiO_2) > 50% en masa (UNE EN 196-2)

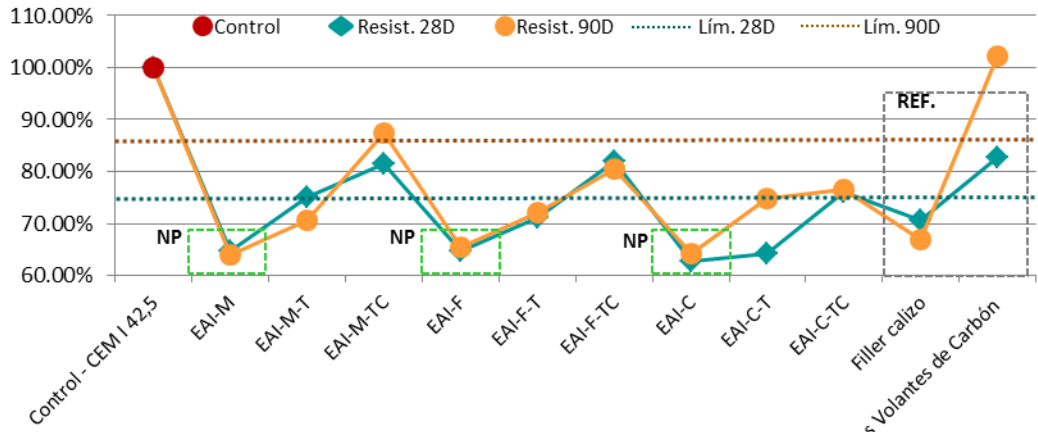
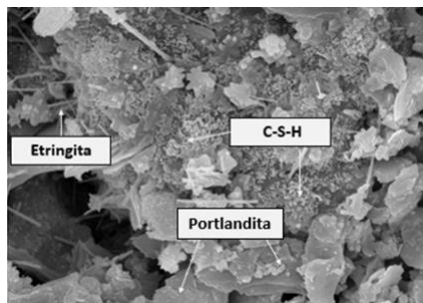


SELECCIÓN DE TRATAMIENTO ÓPTIMO

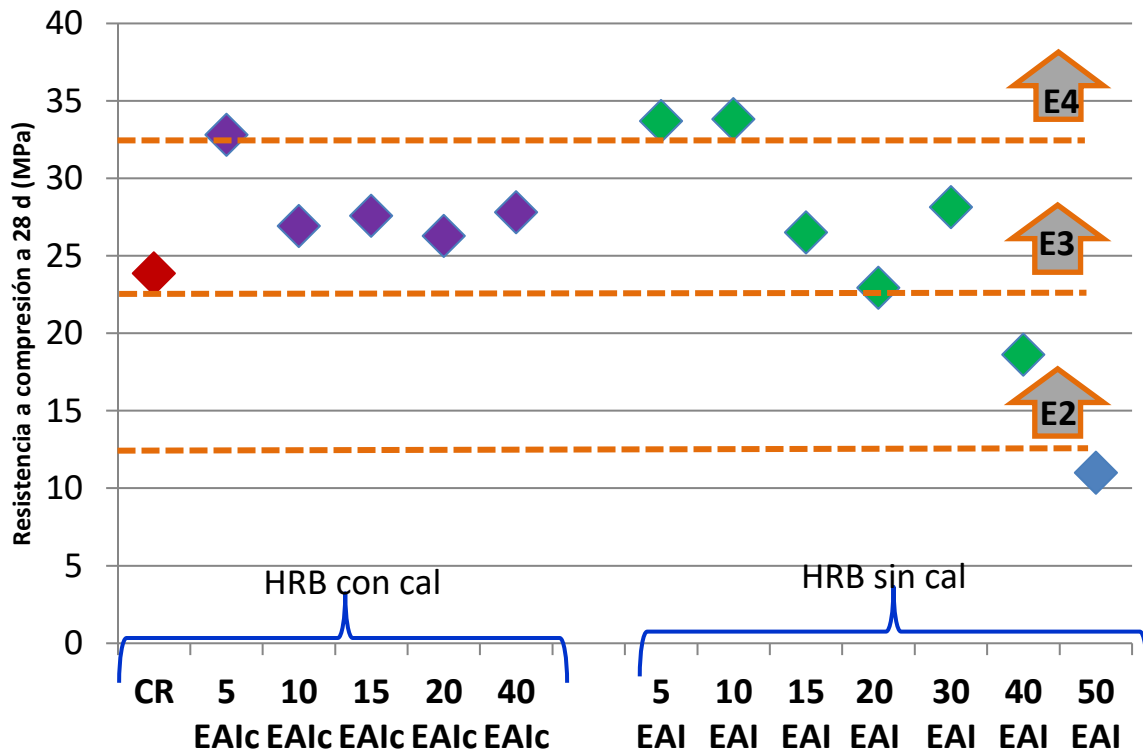


Finura Blaine

R_{30}



Nuevos conglomerantes hidráulicos – HRB-EAI



Contenido de sulfatos SO₃

< 4%

Finura tamiz 90 μm

R₉₀ < 15%

Tiempo inicial de fraguado

> 90 min

Estabilidad de volumen

< 10mm

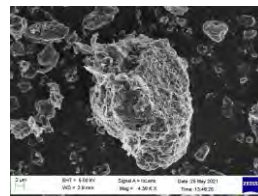
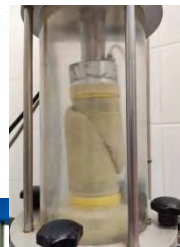
Nuevos conglomerantes hidráulicos – HRB-EAI



MEZCLA OPTIMIZADA



EVALUACIÓN DE PROPIEDADES



Proctor modificado

Índice CBR

Hinchamiento acelerado y libre

Resistencia a compresión

Triaxial CU

Límites de plasticidad

FRX y DRX



MEJORA DE PROPIEDADES DEL SUELO



CONCLUSIONES

ALTO CONTENIDO SiO_2 y CaO

Reacción del óxido de silicio con la Portlandita produce silicato cálcico hidratado (C S H), que tiene propiedades cementantes



ALTA ACTIVIDAD PUZOLÁNICA

Propiedades



ALTO CONTENIDO SiO_2 y CaO

Reacción del óxido de silicio con la Portlandita produce silicato cálcico hidratado (C S H), que tiene propiedades cementantes



ALTA ACTIVIDAD PUZOLÁNICA

+ SiO_2 y CaO

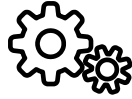
AUMENTO Finura Blaine

I.DE ACTIVIDAD RESISTENTE

Propiedades



Procesamientos



ALTO CONTENIDO SiO_2 y CaO

Reacción del óxido de silicio con la Portlandita produce silicato cálcico hidratado (C S H), que tiene propiedades cementantes



ALTA ACTIVIDAD PUZOLÁNICA

+ SiO_2 y CaO

AUMENTO Finura Blaine

I.DE ACTIVIDAD RESISTENTE

ALTO % APLICACIÓN **EAI vs CLINKER/FILLER/CAL**

Propiedades



HRB



ALTO CONTENIDO SiO_2 y CaO

Reacción del óxido de silicio con la Portlandita produce silicato cálcico hidratado (C S H), que tiene propiedades cementantes



ALTA ACTIVIDAD PUZOLÁNICA

+ SiO_2 y CaO

AUMENTO Finura Blaine
I.DE ACTIVIDAD RESISTENTE

ALTO % APLICACIÓN EAI vs CLINKER/FILLER/CAL

CUMPLIMIENTO REQUISITOS NORMATIVOS

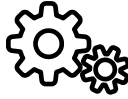
ALTOS VALORES DE R.COMPRESIÓN

CLASIFICACIÓN E3 Y E2

Propiedades



Procesamientos

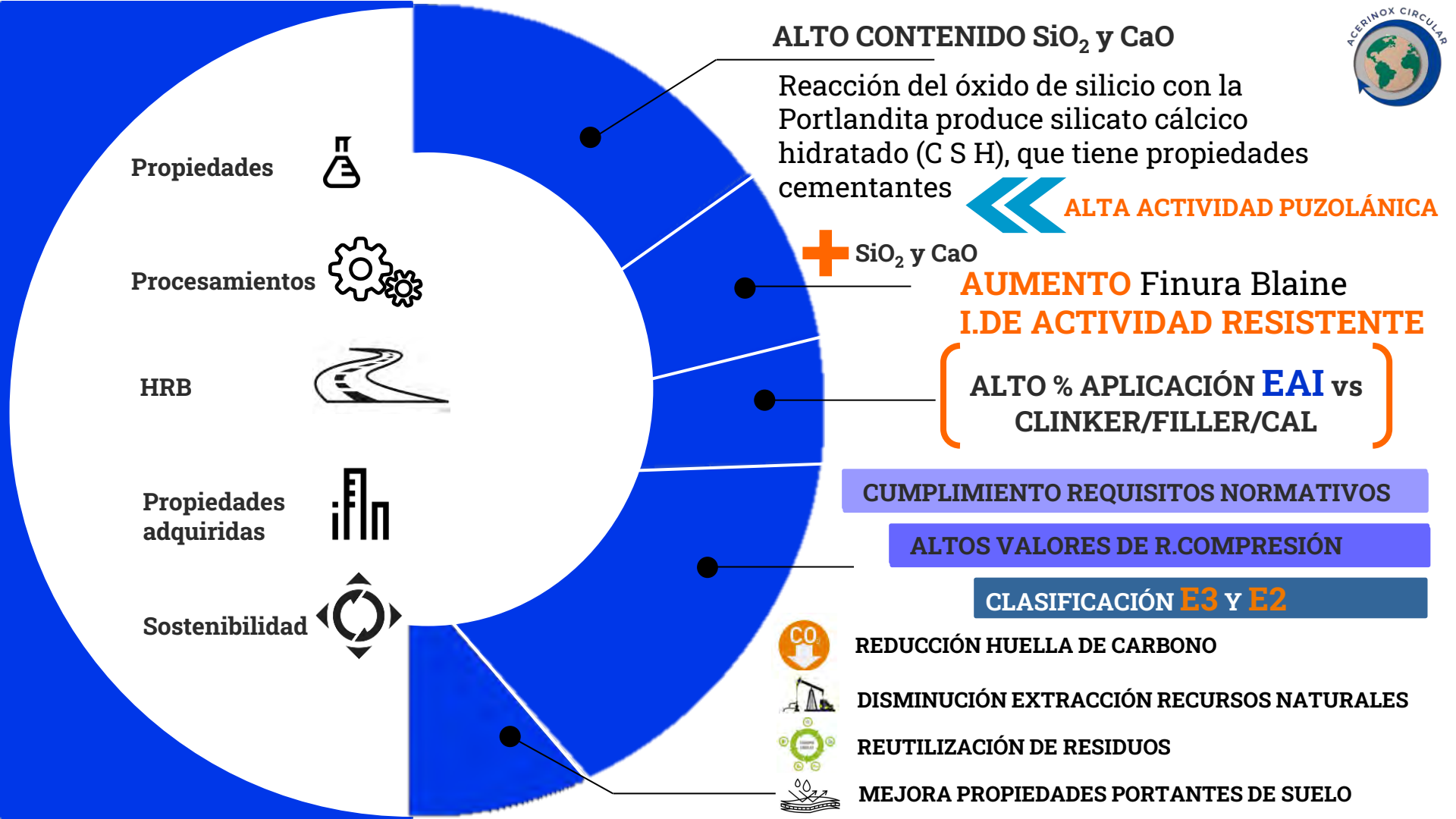


HRB



Propiedades adquiridas





ES POSIBLE CONSTRUIR CARRETERAS CON **ESCORIAS** **DE ACERO INOXIDABLE**



AGRADECIMIENTOS

Investigación avanzada en el ámbito de los residuos industriales de base mineral como materias primas secundarias para la formulación de nuevos productos ecológicos y la creación de bucles de economía circular – CERES



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MARZO 2023



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