Abstract

Urbanization and demographic growth have led to increased carbon dioxide (CO_2) emissions in recent years. Furthermore, construction products and materials industries have contributed significantly to this increase in greenhouse gas emissions due to their significant environmental impact during the extraction and processing of raw materials.

To address this environmental problem, architectural design and civil engineering are trying to implement strategies that enable the use of high-performance materials while minimizing the usage of toxic and dangerous building materials. These efforts also aim to make buildings less energy-consuming during their useful life. Using waste materials, such as Construction and Demolition Waste (CdW), is one of the most promising approaches to address this issue. In recent years, the European Union (EU) has supported recovery strategies focused on using CdWs, as they account for more than 30% of the total waste production in the EU. In this regard, reuse techniques – such as the incorporation of concrete fragments and bricks as road floor fillers – have been the subject of targeted scientific research. However, such techniques only allow partial disposal of construction waste; therefore, the central demand of this doctoral thesis has been:

“Is it possible to obtain CdW-based materials with the same or even better mechanical and environmental performance than conventional construction materials?”

Consequently, this study aims to investigate the use of construction and demolition waste for civil applications: by incorporating waste materials into traditional cement matrix materials, the study intends to take on the challenge of developing “green” building materials.

The initial phase of the research work (Chapter 1) mainly examined the transition from a linear economy model to a circular economy model and its benefits. To resource efficiency, a combination of policies must be implemented to activate cross-sectoral and circular synergies; a higher rate of recycling of waste materials, for example, can relieve the pressure on demand for raw materials by facilitating the reuse of materials that would otherwise have to be dumped and

thereby reducing energy consumption and greenhouse gas emissions related to the extraction and processing of raw materials. In particular, for CdW, literature has shown that it can be incorporated as Recycled Aggregates (RA) into cemented materials and that such action can generate substantial economic and environmental benefits while reducing waste.

Chapter 2 overviews trends and advances in smart and green concrete technology. It examines significant trends, such as using carbon nanotubes for structural monitoring and highlights their potential to improve structural durability. This is because durable and monitored structures can reduce the need for new materials, thus promoting sustainability principles. In addition to the latest innovations in the field of concrete technology, the chapter offers an overview of the use of construction and demolition waste, as well as the regulatory measures governing its management and regulation in Europe and worldwide.

Chapter 3 explores the incorporation of construction and demolition aggregates into mortar, examining the possibility of improving the mechanical properties of recycled aggregates used in building materials through specific additives such as crystallizers. The experimental part of this thesis (Chapter 4) focuses on mortar made from two types of waste materials: Construction and Demolition Waste (CdW) and concrete waste (CON), in place of recycled aggregates (RA) as the production of Standard Sand (SS) is considered to be environmentally impactful, requiring a considerable amount of material resources and energy.

The primary objective of this study was to evaluate the performance of mortar containing different rates of replacement of recycled inert (25%, 50%, 75% and 100%) by investigating key properties such as flexural and compression strength, workability, durability and optimal level of substitution of virgin aggregates. Furthermore, the study assessed the impact of various RA sources (Concrete and construction and demolition waste) and pre-treatment techniques for their improvement from the point of view of physical and chemical characteristics and their consequent effect on the properties of the mortar. In this sense, special attention has been focused to the problem of the high demand for water in AR, which often compromises the mechanical properties of cement compounds.

One of the main results was the optimal level of replacing 50% of standard sand with recycled sand. In-depth experimental investigations revealed that incorporating 50% recycled sand improved mechanical properties, workability, and durability. In particular, the mechanical performance of mixtures containing 50% of RA is comparable – or even superior – to those of traditional mixes containing only SS, thanks to the addition of the optimal amount of superplasticizer. This discovery demonstrates the feasibility of incorporating recycled aggregates into construction practices as a sustainable alternative to raw materials, while preserving the required mechanical properties. (Chapter 5).

The environmental implications of using recycled aggregates in mortar were assessed in Chapter 6, using Life Cycle Assessment methodologies. (LCA). Considerations included greenhouse gas emissions, land use and water consumption in assessing environmental problem and potential benefits. The findings provide valuable insights on the sustainability of incorporating recycled aggregates into mortar, thus facilitating informed decision-making towards environmentally-friendly building practices. The results indicated that incorporating recycled aggregates at 50% and 100% replacement levels significantly reduced the environmental problem associated with sand mining and waste generation, thereby contributing to more sustainable construction practices.

In Chapter 7, the results demonstrate the feasibility of using CdW to produce new building materials with a negative carbon footprint while maintaining the mechanical properties of traditional materials. This approach aligns with the European requirements for the sustainable use of natural resources and promotes a circular economy perspective, that gives a second life to materials that would otherwise be sent to landfills. By utilizing the correct mix design, new alternative paths in the field of concrete technology can be followed. This approach is a significant step towards reducing the environmental impact of the construction industry and promoting sustainable development.