

Development of Sustainable and Resilient Infrastructure Systems Using Recycled Materials and Advanced Techniques

Dr. Yahya Al-Mutairi ^a

^a *King Saud University, Saudi Arabia.*

Abstract

Recent strides in renewable energy technology are making it possible to generate clean and reliable energy right in our cities. This not only boosts energy independence but also helps cut down on carbon footprints. On top of that, using advanced materials in urban infrastructure can significantly improve durability, efficiency, and sustainability. Take nanotechnology, for instance; it allows us to create high-performance materials that are incredibly strong, flexible, and resilient. These materials can be applied in construction, transportation, and water management systems, enhancing the resilience and lifespan of our infrastructure. Moreover, civil engineering is key to designing and implementing sustainable urban infrastructure. From eco-friendly building practices to resilient urban planning, civil engineers are vital in crafting cities that can endure environmental challenges and adapt to changing conditions. The technologies behind construction materials are essential for boosting the functionality of buildings and infrastructure. Innovative construction material technologies have sparked solutions to many issues the construction industry faces, like low energy efficiency and high carbon emissions. Therefore, choosing the right construction materials is crucial for shaping the entire life cycle of infrastructure—from cradle to cradle—and ultimately impacts project costs.

Keywords: Renewable Energy, Advanced Techniques, Recycled Materials.

Introduction

The 21st century has seen an incredible surge in urbanization, with over half of the global population now calling cities home. This swift growth brings a mix of opportunities and challenges for sustainable development. As urban areas expand, they're under increasing strain regarding resources, infrastructure, and the environment [1]. To tackle these issues, the idea of sustainable development has become a key principle in urban planning.

Additionally, natural fibers serve as an effective, budget-friendly, and sustainable option for reinforcing fiber-reinforced polymer composite materials in a variety of construction projects. When we incorporate natural fibers into thermoplastic composite materials, we not only boost performance but also open the door to recycling possibilities. Another exciting avenue in sustainable building is the use of "self-healing" technology. This innovative approach has already been successfully applied to several civil structures in recent years [4].

It's important to note that a significant amount of solid waste is produced when existing buildings are demolished. In fact, in some countries, this waste is recognized as one of the largest contributors to construction and demolition (C&D) debris, making up about 20% to 40% of all waste generated. Unfortunately, only a small fraction of this construction waste is recycled or repurposed instead of relying on natural resources. The push to use construction and demolition waste (CDW) as a substitute for natural aggregates has become a key focus in promoting a circular economy. Each year, around 20 billion tons of natural resources are required globally to produce new concrete, and this demand is projected to increase over the next two to three decades. The demolition process itself is a major source of solid waste, contributing significantly to environmental pollution worldwide, with C&D waste accounting for 20-40% of total rubbish. The chart below illustrates the annual C&D waste generation across various countries, including China, the US, India, Australia, England, France, Italy, and the European Union. In the United States, recycling efforts are more robust; out of 600 million tons of debris from construction and demolition, approximately 75% is recycled. In contrast, reports indicate that less than 40% of C&D waste in China is recycled.

Literature Review

Infrastructure sustainability is a hot topic in civil engineering these days. On the other hand, cone crushers are typically used as secondary crushers and can handle a maximum feed size of 200 mm. Swing hammer mills are quite rare in this context. While impact crushers can also provide a good grain-size distribution, they tend to struggle with materials that are difficult to crush, like reinforcing bars (Hansen, 1986a). Given that jaw crushers yield superior grain-size distribution, we opted to use one to obtain the recycled aggregates for our current project [7].



Fig. 1: Casting Specimen

Methodology

The recycled material was gathered from different construction sites that had been demolished. We sorted through the material to get rid of impurities like bricks and wood, then manually crushed it down to a size of 40 to 50 mm using a 50 kg hammer. Once we had the material at that size, it was fed into the feeding unit of a laboratory jaw crusher with a capacity of 250 kg/hr, after adjusting the movable jaw of the crusher. The pivot mechanism allows us to fine-tune the movable jaw to achieve the desired aggregate size. After making those adjustments, we fed the manually crushed concrete waste into the feeder unit of the jaw crusher. As the material passed through the feeder, it was broken down to the appropriate sizes of 10 to 20 mm. The crushed aggregates that came out of the feeder were then sifted through a series of IS sieves, ranging from 20 mm to 10 mm, in accordance with IS:2386(Part I)-1997, to separate them into various sizes while discarding anything smaller than 10 mm. Any material larger than 20 mm was sent back for re-crushing to ensure we got the right aggregate size. This sieving process also helped remove any leftover mortar traces that had loosened during crushing.

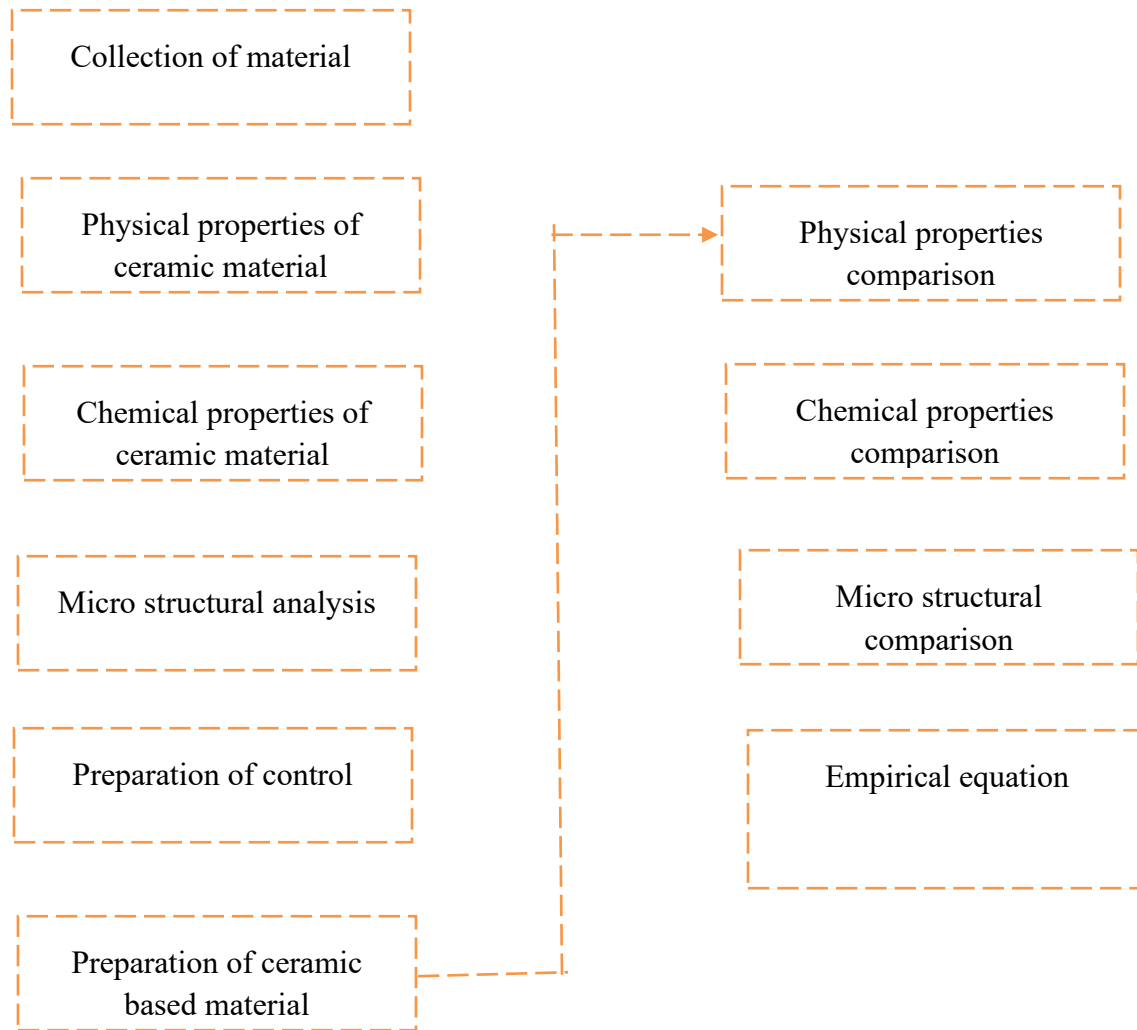


Fig. 2: Research Methodology

Results and Discussion

Building and tearing down structures generates a lot of waste, especially during infrastructure projects like development, modernization, restoration, retrofitting, or demolition.

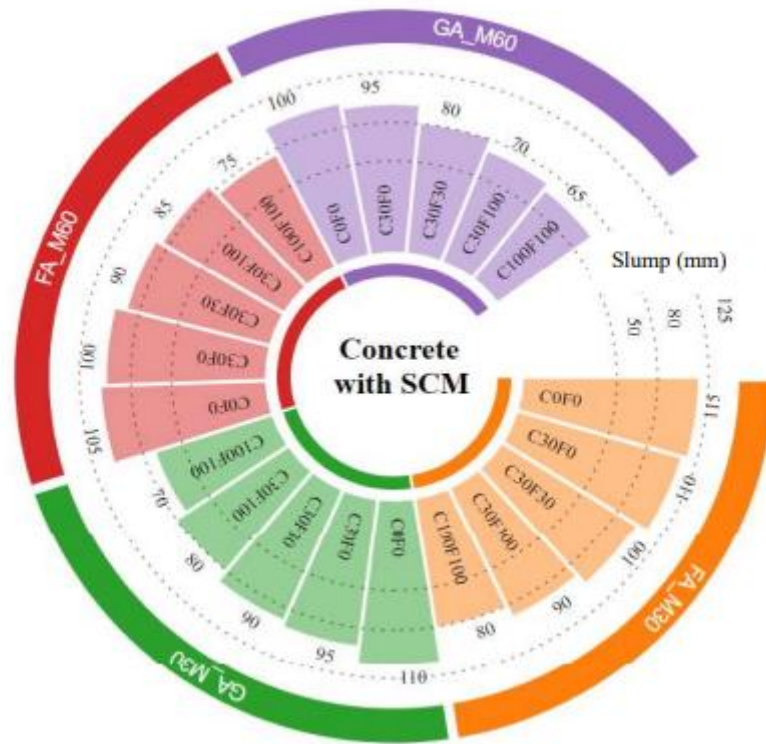


Fig. 3: Slump Variation

Cutting down on energy use and boosting our reliance on renewable energy sources can really enhance energy efficiency in both new and existing buildings. By taking inspiration from nature in how we design materials—creating interactions between the structure, its environment, and the people using it—we open the door to smart materials that ensure a safe, comfortable, and healthy space.

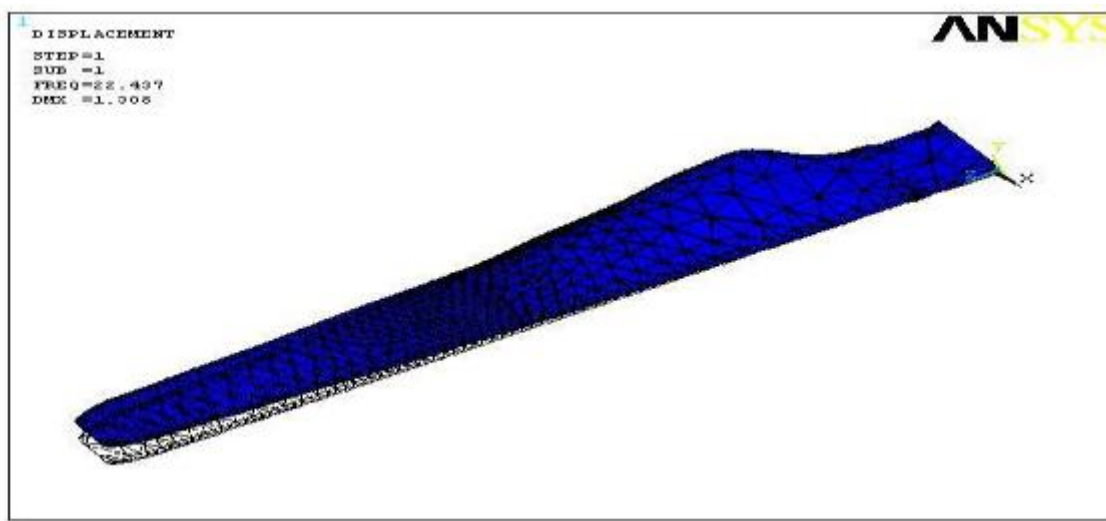


Fig. 4: ANSYS Result

One of the key steps toward sustainability is swapping out high embodied carbon materials for eco-friendly alternatives and using construction and industrial waste to replace natural resources.

Conclusion

Each year, around one million tons of construction and demolition waste (C&D) materials are produced, with most of it finding its way back into construction. We really need to start addressing the damage caused by C&D waste. Unfortunately, many countries don't have the right tools to process these materials, leading to a lot of trash being thrown away instead of being reused to build new structures. While a small fraction of construction waste might get recycled or substituted for natural resources, the focus on using C&D materials instead of natural aggregates is becoming increasingly important for a circular economy. Globally, the production of new concrete consumes about 20 billion tons of natural resources each year, and this figure is expected to rise in the next 20 to 30 years. Innovative materials are essentially traditional materials reimagined with a fresh design approach that prioritizes performance. This performance is increasingly geared towards achieving high energy efficiency, sustainability, and long-lasting buildings and infrastructure.

References

- Coaffee, J. (2008). Risk, resilience, and environmentally sustainable cities. *Energy Policy*, 36(12), 4633-4638. <https://doi.org/10.1016/j.enpol.2008.09.048>.
- Hassan, K. E., Elghali, L., & Sowerby, C. R. (2004). *Development of new materials for secondary and recycled aggregates in highway infrastructure*. Crowthorne, UK: TRL.
- Ranade, R. (2014). *Advanced cementitious composite development for resilient and sustainable infrastructure* (Doctoral dissertation, University of Michigan).
- Pour - Ghaz, M. (2013). Sustainable infrastructure materials: Challenges and opportunities. *International Journal of Applied Ceramic Technology*, 10(4), 584-592. <https://doi.org/10.1111/ijac.12083>.
- Newman, P. (2010). Resilient infrastructure cities. In *Developing living cities: From analysis to action* (pp. 77-106). <https://doi.org/10.1142/7722>.
- Bocchini, P., Frangopol, D. M., Ummenhofer, T., & Zinke, T. (2014). Resilience and sustainability of civil infrastructure: Toward a unified approach. *Journal of Infrastructure Systems*, 20(2), 04014004. [https://doi.org/10.1061/\(ASCE\)IS.1943-555X.0000177](https://doi.org/10.1061/(ASCE)IS.1943-555X.0000177).
- Fiksel, J. (2003). Designing resilient, sustainable systems. *Environmental science & technology*, 37(23), 5330-5339. <https://doi.org/10.1021/es0344819>.
- Minsker, B., Baldwin, L., Crittenden, J., Kabbes, K., Karamouz, M., Lansey, K., ... & Williams, J. (2015). Progress and recommendations for advancing performance-based sustainable and resilient infrastructure design. *Journal of Water Resources Planning and Management*, 141(12), A4015006. [https://doi.org/10.1061/\(ASCE\)WR.1943-5452.0000521](https://doi.org/10.1061/(ASCE)WR.1943-5452.0000521).