Sustainability of Materials: Integrating Principles of Chemistry, Engineering and Mathematics

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Abstract. The growing demand for sustainable resources requires engineering disciplines like principles of mathematics, chemistry and introductory engineering to confront material and energy constraints, along with the importance of reducing waste production. This urgency is particularly pronounced for materials engineers, as their efforts have a profound influence on our future sustainability. Recent advances and discoveries in materials science have the potential to serve as invaluable tools for achieving sustainable progress, provided that materials engineers are aware of these imperatives. They must possess a heightened awareness of the global challenges to sustainability and the insight to discern their role in improving these dilemmas.

Keywords. disciplines, global-challenges, materials-engineering, sustainability.

1. Introduction

The search for more sustainable materials is a pressing demand in a world that is increasingly aware of the environmental implications of industrial production. In this context, the intersection of the fundamental principles of chemistry, engineering and mathematics are important subjects of study. First-year university students are embarking on this journey, aware of the relevance and complexity of the challenge.

The study of the history of engineering materials provides students with an overview of the relative importance of engineering materials over the course of human history. If we review human civilization, whether it is the Vedic Civilization, Mesopotamian Civilization, Egyptian Civilization or the modern era, the ages of mankind are named after the dominant material of the time, namely the Stone Age, the Copper Age, the Bronze Age and the Iron Age. This reflects the importance of materials for mankind and our dependence on them. As noted in Ashby and Johnson (2009), over time this dependency has progressively changed from a reliance on renewable materials to a reliance on non-renewable resources [5].

Environmental and sustainability concerns have therefore become a major focus in today's world, and professional graduates from most technical disciplines must be competent to deal with these complex issues [9].

Understanding the importance of sustainability in the production of materials marks the first step in this research. Even at an early stage in their academic careers, the aforementioned subjects are taught for a solid understanding of the environmental impacts associated with traditional manufacturing processes. This awakening to the need for more sustainable practices is a clear sign of their commitment to a greener future.

At the same time, the introduction skillfully weaves together the triad of subjects - chemistry, introduction to engineering and mathematics - that will be the mainstay of this study. Students realize the importance of a multidisciplinary approach to tackling this complex challenge. It is clear that, despite their early position in the academic journey, they already have an early appreciation of the interconnectedness of these fields of study.

Furthermore, the identification of a gap in knowledge will demonstrate a proactive inclination towards research and filling this space of understanding.

In summary, this introduction signals a promising start to an investigation into the development of

more sustainable materials through the application of chemistry, introductory engineering and mathematics principles. With guidance and practice, students must have the potential to make significant contributions to the advancement of knowledge and the promotion of sustainability in the materials industry.

The discipline of MSE (Materials Science Engineering) is the generation and application of knowledge related to the composition, structure and processing of materials to establish their properties and uses [2].

The need to integrate sustainability into diverse academic curricula is essential for providing students with the skills and insights to help societies become more sustainable [4].

Another effective way to raise the awareness of these issues is to require students to read and critique current scholarly and research articles that address environmental issues. This will give students a broad overview of the issues and the challenges that our world is facing. These assignments should be followed by group discussions and presentations summarizing the substance of the literature. Communications from the Intergovernmental Panel for Climate Change (IPCC) can help to shape the first step of awareness. Seminars from specialist guest speakers belonging to various environmental or government organizations also help to motivate students to think critically about the issues [5].

2. Methodology

The methodology employed in this research is largely based on the course subjects, drawing on knowledge of pre-calculus in mathematics, chemistry and introductory engineering. This multidisciplinary approach aims to investigate how the theoretical and practical principles of these disciplines can be integrated to promote sustainability in the production of materials.

2.1 Mathematics

The pre-calculus concepts were a fundamental pillar for conducting this research. Initially, by exploring sets, we established a solid basis for analyzing the interactions between the constituent elements of the materials. Set theory provided a precise framework for defining parameters and delimiting the essential variables in this paper. Then, by going deeper into functions, we were able to mathematically describe the complex relationships that govern the behavior of materials in different contexts. This approach allowed for more precise modeling and a deeper understanding of the practical implications of our investigations. Subsequently, by exploring the limits, we made progress in optimizing production processes for sustainable materials. Understanding the mathematical limits proved instrumental in the search for maximum efficiency in manufacturing methods. By determining the points at which variables reached critical values, we were able to make strategic decisions that resulted in significant reductions in carbon footprint and waste generation. Thus, the integration of these pre-calculation concepts not only strengthened our methodology, but also proved to be an essential approach for moving towards sustainability in the materials industry..

2.2 Chemistry

Stoichiometry and Valence Bond Theory: Stoichiometry will be fundamental to determining the ideal proportions of reagents in the synthesis of sustainable materials, minimizing the waste of resources. Valence bond theory will be applied to understand the interactions between atoms and molecules, enabling the selection of more efficient and sustainable processes.

2.3 Introductory Engineering

The use of fundamental engineering principles to direct research. Understanding what engineering is, its purposes and how it contributes to solving complex challenges. Analyze the crucial role of the engineer in promoting sustainability in the materials industry. Explore how the application of mathematical and chemical knowledge allows the engineer to develop innovative and sustainable solutions. Investigate the positive impacts that engineering brings to society, highlighting advances in the production of more sustainable materials as a tangible example.

It is the intent of the process to prepare students for potential curriculum integration in the future, as well as for team participation in industry [6].

3. Results

The results of this research reflect the effectiveness of integrating the principles of chemistry, engineering and mathematics in the search for sustainability in the materials industry, as outlined in the methodology.

3.1 Contributions of Chemistry

Applying the concepts of stoichiometry, which deals with the quantitative proportions between reactants and products in a chemical reaction, is crucial for optimizing the synthesis of materials. For example, when producing a polymer from raw materials, stoichiometry makes it possible to determine the precise amount of each component, avoiding excesses that would lead to waste.

In addition, valence bond theory has provided profound insights into the interactions between atoms and molecules. This has enabled the selection of cleaner and more sustainable manufacturing methods [11]. For example, by understanding the chemical bonds involved in the production of ceramics, engineers can choose processes that minimize the emission of pollutants.

According to the “Ingenierie Didactique” framework (Artigue 1988), in order to elaborate fruitful teaching strategies, different types of a priori analyses are needed, which include the analysis of students’ conceptions, their difficulties in understanding, and the analysis of the effect of the usual teaching on students’ conceptual development [3].

3.2 Contributions of Mathematics (pre-calculus)

In the age of science where science is continually developing, and technology rapidly improving, efforts on teaching mathematics – an important scientific branch – with still traditional rules, old approaches and methods are being made [1].

Set theory, a pre-calculus discipline, has played an important role in research. For example, when analyzing the composition of composite materials, set concepts are applied to understand how different elements combine. This makes it possible to determine which elements are essential to achieve the desired properties of the material.

The study of functions has been fundamental to modeling the behavior of materials. For example, when we examined how temperature affects the strength of a material, we used functions to mathematically describe this relationship. This allowed to accurately predict how the material would behave under different temperature conditions.

Understanding limits, another topic of pre-calculus, played a crucial role in optimizing production processes. For example, when adjusting the settings of a production machine, we used limit concepts to determine the point at which efficiency was maximum. This helped us to minimize energy consumption and waste production.

4. Discussion and conclusion

The discussion of the results obtained in this research highlights the critical importance of integrating the principles of chemistry, introductory engineering and mathematics to drive sustainability in the materials industry. Each discipline plays a key role in advancing sustainable practices.

By applying stoichiometry and valence bond theory, concepts intrinsic to chemistry, a more precise and efficient formulation of materials is achieved. This results in a considerable reduction in waste and a notable improvement in the life cycle of products, representing not only a saving in resources, but also a positive impact on the environment.

The use of mathematical concepts, such as sets, functions and limits, provided a solid foundation for modeling and optimizing production processes. This quantitative approach was a decisive factor in achieving notable efficiency gains, demonstrating clearly and unequivocally how sets, functions, limits in mathematics became a valuable tool in the quest for sustainability.

It is also important to note that the integration of these disciplines has generated surprising synergies. The interaction between chemistry and mathematics, for example, has enabled a systematic and precise approach to understand how to design materials with specific characteristics. Similarly, the combination of engineering with chemistry and math concepts has triggered innovations in production processes, resulting in significant reductions in environmental impacts.

These results underline that tackling complex challenges requires an interdisciplinary and collaborative vision. The research highlights the urgent need to make students aware of the interdependence of these disciplines and their relevance to sustainability. It is imperative that engineers and materials scientists are aware of the crucial role they play in mitigating environmental impacts.

Ultimately, the multidisciplinary approach presented in this research offers a promising way forward in the search for more sustainable materials. As we face increasingly pressing global environmental challenges, the integration of knowledge and collaboration between diverse disciplines becomes even more essential to shape a greener and more resilient future in the materials industry.

Although strongly grounded in an engineering discipline, the emphasis of these programmes is on sustainable development, the problems that are created by human activities and on the contribution of the engineer to solving them [8].

This research highlights clearly that an interdisciplinary approach is essential for tackling complex challenges and achieving significant advances in the sustainability of materials. The academic community is therefore encouraged to recognize the importance of working together across disciplines and to promote an ongoing awareness of the interdependence of knowledge.

As we face increasingly pressing global environmental challenges, it becomes essential to adopt a unified and collaborative approach in the search for sustainable solutions. Integrating the principles of chemistry, engineering and mathematics in the materials engineering course offers a promising path towards building a greener and more resilient future, benefiting not only industry, but society as a whole.

We believe that our programmes, modules, learning activities and materials as described in this paper correspond to the engineering specification for sustainable development education recommended by the Sustainable Development Education Panel, and contribute effectively to achieving the common aim, i.e. ``to enable people to develop knowledge, values, and skills to participate in decisions about the way we do things individually and collectively, both locally and globally, that will improve the quality of life now without damaging the planet for the future" [10].

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