METHODOLOGY FOR MATERIAL SELECTION IN MECHANICAL DESIGN

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ABSTRACT

This work develops a structured methodology for material selection in mechanical engineering design, aiming to guide engineers in choosing materials that meet the technical, economic, and environmental requirements of the projects. Based on a detailed literature review, this study proposes a rigorous and well-founded selection methodology based on five fundamental steps: identification of needs, collection of information on materials, analysis and comparison of properties, use of auxiliary tools, and justified decision-making. The main results indicate that the use of a systematic approach improves the accuracy in material selection and increases efficiency in project development. The proposed methodology facilitates informed decision-making and reduces the risk of failures, making the project more sustainable and economical. It is concluded that the adoption of this approach significantly contributes to improving the quality and durability of products in mechanical engineering projects.

Keywords: Material Selection. Mechanical Design. Methodology.

1. INTRODUCTION

The materials selection process is a fundamental step in mechanical engineering projects, directly impacting the performance, durability, and efficiency of the products developed. This work aims to structure a detailed methodology to guide engineers and professionals in the choice of materials, considering the multiple requirements and challenges encountered in industrial and mechanical design contexts. The importance of this topic is highlighted by the growing demand for solutions that guarantee products with high reliability, sustainability, and that effectively meet the specific performance requirements of each application.

Choosing appropriate materials for a project is a complex and often challenging issue, as it involves analyzing a range of criteria such as mechanical strength, thermal behavior, corrosion resistance, and cost-effectiveness. Ashby (2005) and Callister and Rethwisch (2014) emphasize the importance of careful material selection, pointing out that this choice can determine the success or failure of a product under real operating conditions. Furthermore, the diversity of available materials and the development of new materials with specific properties increase the complexity of the selection process, requiring a systematic and informed approach. Existing literature provides a significant basis on criteria and methodologies; however, the increasing demands for sustainability and energy efficiency, as well as economic constraints, motivate new research that incorporates these demands into the material selection process.

A literature review on the subject is relevant not only to consolidate existing knowledge, but also to investigate strategies and criteria for material selection. The complexity of industrial contexts justifies the need for an in-depth analysis that synthesizes the main concepts and recommended practices. Ultimately, this analysis will lead to the proposition of a methodology to assist in the material selection process. Thus, a detailed literature review is an appropriate methodological approach for the proposed investigation, enabling a broader understanding of the variables involved and the methods available for effective material selection.

In this sense, the central objective of this article is to develop a structured methodology for material selection in mechanical projects, integrating different aspects and selection criteria, enabling more assertive choices in mechanical projects.

2. LITERATURE REVIEW

Material selection in mechanical design is a fundamental topic in engineering and has been widely discussed due to the direct impact of materials on the performance, durability, and cost of final products. This topic aims to present the main concepts available in the literature related to this subject, from mechanical design, properties and types of materials in mechanical design to the different criteria for material selection.

2.1 MECHANICAL DESIGN

Initially, it is necessary to define a project. A project consists of a series of activities with a well-defined beginning and end, aimed at achieving predetermined objectives and using resources that are always limited. In a product design project, the purpose is to develop a concrete product, usually specified based on cost, quality, and time criteria, which are the expected results of the activities carried out in the project. (ANTÓNIO; MELO, 2019)

Within the context of Engineering, Norton (2013) defines a project as: "The process of applying various scientific techniques and principles in order to define a device, method or system detailed enough to allow its implementation".

According to Shygley (2015), "Designing is formulating a plan to meet a specific need or solve a problem. If the plan results in the creation of something concrete, then the product must be functional, safe, reliable, competitive, and suitable for use, manufacture, and marketing."

In Mechanical Engineering, the main objective is to dimension and model mechanical components, as well as select the most suitable materials and manufacturing processes, so that the resulting equipment or structure performs its function without failure. This requires the engineer to be able to calculate and predict the failure modes and conditions of each element, designing it to avoid such failures, which implies performing a stress and deflection analysis for each part. (NORTON, 2013)

Project planning establishes a process for creating essential information and ensuring it is delivered to the appropriate people at the right time. This information includes product requirements, concept sketches, functional diagrams, three-dimensional models, drawings, material choices, and any other representation of decisions made throughout product development. (MOTT; VAVREK; WANG, 2018)

Design problems are almost always open-ended in nature. They do not have a single or "correct" solution, although some alternatives stand out in quality compared to others. For this reason, a designer's main tool is an open mind: the willingness to explore all possible alternatives. However, adopting a broad approach results in a wide variety of options, making it necessary to have a method to distinguish the excellent from the merely satisfactory. (ASHBY, 2005)

Developing an engineering project, in which material selection is one of the steps, is a process that combines innovation with frequent repetition and involves constant decision-making. At times, it is necessary to decide with very little information; at other times, with the exact amount of data or even with an excess of information that may be partially conflicting. Often, decisions are made provisionally, with the possibility of adjustments as new information emerges. In all these situations, the designer must be comfortable with the role of making decisions and solving problems. (SHYGLEY, 2015)

Choosing the material for a machine part or structural component is one of the most crucial decisions a designer faces. Generally, this choice occurs before the part's dimensions are defined. After selecting the process to create the desired geometry, as well as the material to be used (both inseparable), the designer can then dimension the component in a way that prevents loss of functionality or keeps the risk of such loss at an acceptable level. (SHYGLEY, 2015)

Material selection in mechanical design is a critical step that directly influences system characteristics such as strength, functionality, and durability. In many cases, the required strength of a component is fundamental in determining its geometry and dimensions, making this consideration a central aspect of the design. Beyond strength, other characteristics such as distortion, wear, and corrosion must also be carefully evaluated. System safety and reliability are equally important, as are manufacturability and cost, which impact the project's economic viability. Aspects such as weight, service life, and thermal properties also play significant roles, as do more subjective factors like style and form. (SHYGLEY, 2015)

All these characteristics interact in a complex way, requiring a holistic analysis to ensure that each element of the system functions effectively and efficiently. The choice of material not only determines the dimensions and processing, but also impacts the joining of elements, reflecting in the overall configuration of the system. (SHYGLEY, 2015)

2.2 MATERIAL PROPERTIES IN MECHANICAL DESIGN

Material properties are intrinsic characteristics that determine a material's behavior under different conditions of use and manufacturing processes. In mechanical design, these properties are fundamental to ensuring the functionality, safety, and durability of products. Proper material selection allows not only for performance optimization and cost reduction, but also for the prevention of mechanical failures and increased efficiency of parts, machines, equipment, and systems.

Each material can be seen as possessing a specific set of attributes: its properties. What the designer seeks, however, is not the isolated material, but a particular combination of these properties, that is, a property profile. (ASHBY, 2005)

The properties of materials are detailed in the works of Callister and Rethwisch (2014), Chiaverini (1986), Ashby (2005), Simêncio (2017), and Zolin (2010). Below are some of the main material properties to be considered in mechanical design.

Density (ρ): The mass per unit volume of a material, expressed in kg/m^3. It is essential for determining the weight of the final component and is an important factor in applications that require lightness.

Elastic Modulus (E): Also known as Young's modulus, it indicates the stiffness of a material, that is, the relationship between stress and strain in the elastic region. A high modulus means a stiffer material that is less deformable under load.

Yield Strength (σe): The maximum stress a material can withstand before undergoing permanent deformation. Important for determining its ability to withstand loads without suffering irreversible deformation.

Tensile Strength (σr): The maximum stress a material can withstand before breaking. Essential for assessing safety and structural integrity.

Poisson's ratio (ν): The ratio between transverse contraction and longitudinal extension in a loaded part. It aids in the analysis of volumetric deformation.

Ductility: The ability of a material to deform plastically before fracturing. Ductile materials withstand greater deformations, making them useful in applications that require energy absorption.

Toughness and Resilience: Toughness measures a material's ability to absorb energy before fracture, while resilience is the energy absorbed within the elastic limit. Essential for materials subjected to impacts and variable loads.

Hardness: A material's resistance to permanent deformation (scratching or indentation). Indicative of resistance to wear and abrasion.

Thermal Conductivity (k): The rate of heat transfer through the material. Important for applications where heat dissipation or insulation is critical.

Thermal Expansion (α): The measure of a material's expansion when heated. Essential for predicting dimensional changes with temperature variations.

Specific Heat (c): The amount of heat required to raise the temperature of a unit mass of the material. Important for understanding the thermal response in heating or cooling operations.

Corrosion Resistance: The material's ability to resist deterioration caused by chemical reactions with the environment, essential in applications subject to exposure to aggressive media.

Fatigue Resistance: The ability of a material to withstand cyclic loads without failing, fundamental in parts subjected to repetitive stress, such as shafts and structural components.

The properties of materials are strongly influenced by a variety of factors that must be considered in engineering projects. Chemical composition plays a crucial role, as the inclusion or removal of elements alters fundamental characteristics such as strength and ductility. Furthermore, heat and surface treatments modify the structure and improve properties such as corrosion resistance and hardness. Processes such as plastic deformation and the manufacturing method itself also affect the mechanical behavior of the material, impacting its durability and strength in different applications. (CALLISTER AND RETHWISCH, 2014)

Environmental factors, such as temperature, humidity, and exposure to corrosive substances, can degrade the properties of materials over time, resulting in fatigue and even structural failures. Temperature, in particular, can reduce strength and alter thermal and electrical conductivity. Additives or reinforcing materials are used to adjust specific properties, while external factors such as shocks and vibrations can accelerate degradation. These factors, combined, reinforce the importance of understanding and controlling the variables that can impact the performance of materials in mechanical designs. (CALLISTER; RETHWISCH, 2014)

2.3 TYPES OF MATERIALS FOR MECHANICAL PROJECTS

In mechanical engineering projects, material selection is crucial, as each type of material has distinct characteristics that affect the performance, durability, and cost of the final product. Materials for these applications in mechanical engineering projects can be classified into four main categories: metals, ceramics, polymers, and composites.

Metals are formed by one or more metallic elements, such as iron, aluminum, copper, titanium, gold, and nickel, and often also contain small amounts of non-metallic elements, such as carbon, nitrogen, and oxygen. In metals and their alloys, the atoms are arranged in a highly organized manner and exhibit high density compared to ceramics and polymers. In terms of mechanical characteristics, these materials are generally rigid, strong, ductile (capable of undergoing large deformations without breaking), and possess good fracture resistance, making them ideal for use in structural applications. (CALLISTER; RETHWISCH, 2014)

Metals have free electrons in their atomic structure. This characteristic explains several of their properties, such as high thermal conductivity in addition to high electrical conductivity. (ZOLIN, 2010)

Ceramics are compounds formed by the combination of metallic and non-metallic elements, commonly found in the form of oxides, nitrides, and carbides. Some examples of common ceramic materials include aluminum oxide (or alumina, Al_2O_3) , silicon dioxide (or silica, SiO_2) , silicon carbide (SiC), and silicon nitride (Si_3N_4) . Traditional ceramics, such as those made from clay minerals (e.g., porcelain), as well as cement and glass, also belong to this class. Regarding mechanical behavior, ceramics are typically rigid and strong materials, with stiffness and strength values comparable to those of metals. Additionally, they tend to be very hard. (CALLISTER; RETHWISCH, 2014)

Traditionally, ceramics exhibit high fragility (low ductility) and are susceptible to fracture. However, new ceramics have been developed with improved fracture resistance and are used in kitchen utensils, knives, and even automotive engine parts. In general, ceramics are heat and electrical insulators, exhibiting low electrical conductivity, and are more resistant to high temperatures and aggressive environments than metals and polymers. (CALLISTER; RETHWISCH, 2014)

Polymers encompass widely known materials such as plastics and rubbers. Many are organic compounds, primarily based on carbon, hydrogen, and other non-metallic elements such as oxygen, nitrogen, and silicon. These materials have large molecular structures, generally in the form of chains with a carbon atom skeleton. Chiaverini (1986) defines plastics as: "an arbitrary group of artificial materials, generally of synthetic organic origin, which at some stage of their manufacture acquired the plastic condition during which they were molded, with the application of pressure and heat". Well-known examples include polyethylene (PE), nylon, polyvinyl chloride (PVC), polycarbonate (PC), polystyrene (PS), and silicone rubber.

Polymers generally exhibit low density and mechanical properties different from those of metals and ceramics, being less rigid and resistant. However, due to their lightness, the stiffness-to-mass ratio of many polymers can be comparable to that of metals and ceramics. Furthermore, many polymers are highly ductile and malleable, which facilitates molding into complex shapes. Chemically, they are relatively inert and unreactive in various environments. However, a significant disadvantage is their tendency to soften or decompose at moderate temperatures, which can restrict their applications. Additionally, polymers have low electrical conductivity and are non-magnetic. (CALLISTER AND RETHWISCH, 2014).

Composites are materials formed by combining two (or more) individual materials from the categories discussed previously—metals, ceramics, and polymers. The purpose of creating a composite is to bring together a combination of properties that are not offered by any single material, taking advantage of the best characteristics of each component. There are many possible combinations between metals, ceramics, and polymers, resulting in a wide variety of composites. Most composites are composed of two distinct phases: one known as the matrix and the other as the dispersed phase. The combination of the properties of these phases, along with the relative proportion of each and the geometry of the dispersed phase, defines the characteristics of the material. Composites can be classified as: reinforced (with particles or dispersed fibers); fiber-reinforced (continuous—aligned or discontinuous—short fibers, which can be aligned or randomly oriented); and structural (laminates or sandwich panels). (ZOLIN, 2010)

Fiberglass is one of the best-known composites, where small glass fibers are incorporated into a polymer matrix (usually epoxy or polyester). The glass fibers are quite rigid and strong (although brittle), while the polymer provides flexibility. As a result, fiberglass is a relatively rigid, strong, and flexible material, in addition to having low density. (CALLISTER; RETHWISCH, 2014).

2.4 CRITERIA FOR SELECTING MATERIALS

Different types of approaches and strategies for material selection in mechanical design projects are observed in the literature.

Ashby and Cebon's (1993) article presents a software-implemented procedure for material selection in mechanical design. This procedure uses material selection charts, which display property data and performance indices, combining properties that govern performance in specific applications. The approach also allows for the simultaneous selection of material and shape using optimization methods. Furthermore, the article discusses how material selection should consider both intrinsic properties and the ideal shape to maximize structural efficiency and component performance.

In the study, the use of performance indices allowed for a more precise and efficient approach to choosing materials for specific applications, enabling an in-depth analysis of combinations of properties needed in engineering projects.

The work of SM Sapuan (2001) explores the development and use of Knowledge *-Based Systems* (KBS) to assist in material selection in mechanical design. The study highlights the importance of KBS in the context of concurrent engineering, which seeks to optimize design and manufacturing processes by integrating various stages of the product lifecycle. The article discusses the role of material databases, which store and organize information on material properties, facilitating the selection of lighter, stronger, and more economically viable materials. Sapuan emphasizes the efficiency of KBS in quickly selecting materials based on rules and specialized knowledge, demonstrating this application in the choice of polymeric compounds. The article concludes that KBS is an essential tool in material selection, especially in complex engineering contexts that require rapid and integrated decisions.

The article by Ferrante, Santos, and Castro (2000) examines material selection as an essential interdisciplinary technical activity in mechanical design. Material selection has evolved from an empirical practice to a structured methodology, driven by tools such as Material Property Maps and Merit Indices, concepts developed to help engineers identify ideal materials based on multiple properties, such as stiffness and corrosion resistance. The article highlights the importance of a collaborative approach involving experts from different areas, as factors such as cost, durability, and environmental impact require an integrated perspective.

The study also presents two case studies: one on the choice of materials for centrifuge rotors and another on furniture design. The first illustrates how suitable materials can be selected to maximize structural performance and minimize weight, while the second explores selection focusing on physical comfort and aesthetics. The authors conclude that material selection benefits significantly from interdisciplinarity, and methods such as the use of property maps and decision matrices are effective in addressing the diverse requirements of complex engineering projects.

Leigh Holloway's (1998) article discusses how material selection in engineering can consider environmental impact by integrating mechanical and environmental performance criteria. The methodology uses material selection charts proposed by Ashby (1993), which include air and water pollution indices. The study shows how environmental factors, such as emissions and waste, can be aggregated to simplify analysis and facilitate environmentally conscious design decisions.

The methodology involves steps to create indices that maximize desired properties while minimizing environmental impacts, such as CO_2 and NOx emissions . The article also presents examples of applying these indices to the selection of materials for products, such as beverage containers, demonstrating how materials with lower environmental impact can be identified and prioritized. Despite limitations, such as the scarcity of environmental data and the complexity of the calculations, the article suggests that adapting Ashby's charts is a useful tool for designers, allowing for informed choices that balance functionality and sustainability.

The work of Samuel Scheleski (2015) addresses the application of material selection methodologies in the agricultural sector, especially for the design of machinery and implements. The study uses the Ashby methodology (1993), which facilitates innovation by considering a wide range of materials. The work includes the analysis of methods and tools, such as the CES software, and conducts a case study applying the methodology to the fairing of a grain harvester. The main conclusions include: the suitability of Ashby's methodology for optimizing product development; the infeasibility of developing a customized material selection system for the sector; and the importance of synthesis and similarity procedures, which, although still needing more advanced tools, help to expand the designers' vision.

Yuri Walter's thesis (2006) proposes a methodology and an information system for the selection of materials and manufacturing processes in design. The author explores the difficulties of integrating design and materials engineering, addressing the importance of a flexible system that caters to everything from conceptual design to manufacturing.
Walter highlights the inadequacy of traditional material selection systems for design in Brazil and suggests the creation of a distributed Digital Information System (DIS), along with a "Material Library" – a physical collection of material samples for consultation. The thesis

analyzes existing material selection methods, the interaction between design and materials, and proposes adaptations to optimize material selection based on local production and market needs.

Within this context of design and materials selection, Norton (2013) states that: “The advent of the computer has brought about a true revolution in engineering design and analysis. Problems whose solution methods were known literally for centuries, and which remained practically unsolvable due to high computational demands, can now be solved in minutes on low-cost microcomputers.”

The use of computational tools such as CAD (Computer-Aided Design) and CAE (Computer-Aided Engineering) has proven fundamental in mechanical design, as it allows for the creation and analysis of virtual models with precision and efficiency. CAD facilitates the creation of technical drawings and 3D modeling, enabling engineers to visualize and modify designs before production. CAE, on the other hand, is used for simulations that evaluate the design's performance under various conditions, such as stress, temperature, and dynamics, helping to identify flaws and optimize designs.

Material selection is a critical aspect that integrates CAD and CAE, as the properties of the chosen materials directly influence the system's behavior. Through analyses performed in CAE, it is possible to test different materials and their characteristics, such as strength, durability, and cost, ensuring that the design not only meets functional requirements but is also economically viable. This synergy between CAD, CAE, and material selection results in a more robust and efficient design process, allowing the creation of high-quality, high-performance products for the market. (SHYGLEY, 2011)

3. METHODOLOGY

As discussed, the materials selection process is a fundamental step in the development of successful projects in various areas of engineering and industry. The choice of materials will directly impact the performance, durability, and efficiency of the final product. Therefore, based on a review and in-depth analysis of the literature on the subject, a methodology for materials selection in mechanical projects is proposed, consisting of 5 stages: 1. Identification of needs and requirements, 2. Collection of information on available materials, 3. Analysis and comparison of material properties, 4. Use of auxiliary tools and resources, and 5. Decision-making and justification of the choice.

3.1 STAGE 1: IDENTIFICATION OF PROJECT NEEDS AND REQUIREMENTS

The first step in the materials selection process is to clearly understand the needs and requirements of the project in question. Each application presents unique demands, which must be carefully analyzed to define which properties and characteristics are crucial for the performance of the component or system.

During this phase, it is important to involve the entire project team and relevant stakeholders to gain a comprehensive understanding of project expectations and goals. Key issues to consider include:

1. Mechanical requirements:

Mechanical requirements involve initially determining the loads and forces that the material will need to withstand. Materials must have adequate properties such as strength, yield strength, modulus of elasticity, toughness, hardness, and other properties related to the material's ability to withstand loads, deformations, and specific project working conditions.

2. Thermal requirements:

Thermal requirements are related to evaluating the temperature variations that the material will face during operation. Therefore, it involves considering properties such as thermal conductivity, thermal expansion, specific heat, and corrosion resistance at different temperatures. These factors influence heat dissipation, dimensional stability, energy efficiency, thermal behavior, and component durability, ensuring optimal performance under varying temperature conditions.

3. Environment and operating conditions

Environmental requirements and operating conditions are important factors in the choice of materials for mechanical designs. These involve considerations of the environments in which the components will be used and the conditions to which they will be exposed, such as temperature, humidity, and the presence of corrosive or aggressive substances, among others. Proper material selection, taking these requirements into account, is fundamental to ensuring durability, corrosion resistance, dimensional stability, and overall design performance under real operating conditions. Choosing materials appropriate for the environment and operating conditions contributes to the efficiency, safety, and service life of mechanical components and structures.

4. Weight and size restrictions:

Size and weight requirements are important criteria in the selection of materials for mechanical projects. They refer to the physical dimensions of the components and the density of the materials used. These requirements are relevant to ensure structural efficiency, manufacturing feasibility, and proper transportation of components. Furthermore, by selecting materials based on these requirements, it is possible to optimize the performance, functionality, and economy of mechanical designs. If the project requires lightweight or compact components, choose materials with high specific strength or low density.

5. Cost considerations:

Cost requirements are essential factors in the selection of materials for mechanical projects. They involve considerations of material price, production costs, maintenance, and operation. The search for materials that meet the desired performance requirements in the most economical way is fundamental to making the project viable, ensuring it is competitive and financially feasible. Careful cost-benefit analysis of materials is crucial to optimize resources and obtain the best return on investment in the mechanical project.

6. Standards and regulations:

Standards and regulations are essential guidelines for material selection in mechanical projects. They establish quality, safety, and performance standards that must be followed to ensure project compliance with industry-specific technical standards and regulations. Adopting materials that meet regulatory requirements ensures the project is safe, reliable, and complies with guidelines established by regulatory authorities and bodies. This is fundamental to avoiding legal problems, guaranteeing the quality of the final product, and protecting the health and safety of users and the general public.

7. Availability of Material

Availability requirements refer to the ability to obtain the materials needed for a mechanical project. It is essential to consider whether the chosen materials are available on the market, in sufficient quantities, and at a reasonable cost. Furthermore, it is important to assess whether the production of the materials meets the project's demand and whether the suppliers are reliable and capable of consistently providing the materials. Choosing readily available materials ensures that the project can be executed without delays or problems related to shortages or lack of necessary materials.

8. Compatibility with other materials

The requirements for compatibility with other materials refer to the ability of the chosen material to interact appropriately and harmoniously with other materials present in the mechanical design. It is important to consider whether the selected materials are compatible in terms of their physical, mechanical, and chemical properties in order to avoid problems such as corrosion, excessive wear, or unwanted reactions between materials. Choosing compatible materials ensures the integrity and efficiency of the design, avoiding incompatibilities that could lead to failures or performance problems.

9. Process Compatibility

Process compatibility requirements refer to the suitability of the chosen material for the manufacturing and assembly processes used in the mechanical design. It is important to select materials that can be easily processed and are compatible with the manufacturing and assembly techniques employed. Materials with good process compatibility ensure more efficient production, reducing costs and increasing project viability. Furthermore, choosing materials compatible with manufacturing processes can contribute to obtaining parts with greater dimensional accuracy and quality, resulting in a higher-performing final product.

10. Environmental impact and sustainability

Environmental impact and sustainability requirements for material selection in mechanical design refer to considering environmental effects throughout the product's lifecycle. It is important to select materials that have a lower environmental impact, from raw material extraction to the final disposal of the product after its end-of-life. This includes analyzing the efficient use of natural resources, reducing greenhouse gas emissions, minimizing energy consumption, and the ability of materials to be recycled or reused after disposal. Sustainability in material selection aims to ensure the preservation of natural resources and the reduction of environmental damage, contributing to more responsible and conscious development in mechanical design.

3.2 STAGE 2: COLLECTING INFORMATION ABOUT AVAILABLE MATERIALS

In the second stage of the materials selection process, after identifying the project's needs and requirements, it is necessary to conduct a thorough collection of information about the materials available on the market. This stage is extremely important, as the quality of the material choice depends directly on the accuracy and comprehensiveness of the information collected. Proper data collection on available materials will allow engineers and professionals to perform a detailed comparative analysis to select the most suitable option for each specific application.

To collect information, a variety of sources can be used, including:

1. Material catalogs and databases: Many manufacturers and research institutes provide catalogs and databases that offer detailed information on the properties, applications, and characteristics of materials. These resources can be an excellent source of reference for understanding the available options.

2. Technical specifications: Consulting the technical specifications of materials provides accurate information about their mechanical, thermal, electrical, and chemical properties. These specifications help determine if the materials meet the specific project requirements.

3. Books and technical literature: Numerous publications and technical literature dedicated to materials science provide detailed information on different types of materials, their properties, and their applications. Reading these sources can provide a solid foundation for informed decision-making.

4. Consulting experts: Talking to materials science specialists, engineers, and other professionals in the field can provide valuable insights into the applicability of certain materials for the project in question.

5. Tests and trials: In some cases, it is possible to carry out specific tests and trials to evaluate the properties and behavior of materials under specific operating conditions. This data can be crucial for the final decision-making process.

The information gathering process must be meticulous and comprehensive, allowing professionals to have a complete overview of the available options and their characteristics. This step is crucial to avoid inappropriate choices and ensure that the selected material meets all the project's needs and expectations.

3.3 STAGE 3: Analysis and Comparison of Material Properties

After gathering information about the available materials, it is necessary to analyze and compare the properties of each option. This analysis stage is essential to understand how the materials behave under different conditions and how their properties meet the specific project requirements. This detailed analysis will allow engineers and professionals to make an informed decision and choose the most appropriate option for each application.

To achieve this, it is recommended to compare the most relevant properties of each material type for the project in question to gain a comprehensive overview. During the comparison, it is helpful to use scoring criteria or decision matrices to assign weights and importance to each property, depending on its relevance to the project. This will help make the process more objective and systematic, avoiding subjective decisions. Furthermore, consulting experts and conducting specific tests or trials can complement the analysis and provide additional data for decision-making.

It is important to emphasize that there is not always a perfect material that ideally meets all requirements. In most cases, it is necessary to compromise between the different properties and characteristics of the materials to find the best solution for the project.

3.4 STAGE 4: USE OF TOOLS AND AUXILIARY RESOURCES

In the materials selection process, the analysis and comparison of material properties can be quite complex, especially in projects involving multiple requirements and specific criteria. In this context, the use of auxiliary tools and resources plays a fundamental role, providing support and streamlining the decision-making process. These tools range from simulation and testing software to specific technical guidelines and standards. By using these tools, engineers and professionals can obtain more accurate information and make more informed decisions, ensuring the selection of the most suitable material for each application.

Some of the main tools and auxiliary resources used in the materials selection process include:

1. Simulation software: Computer simulation software allows for the analysis of material behavior under different operating conditions, such as stress, temperature, and chemical environment. These simulations can help predict material performance in real-world situations and assist in choosing the best option for the project.

2. Technical guidelines and standards: In some cases, there are specific technical standards and guidelines that guide the selection of materials for particular applications. Following these standards can ensure that the project conforms to recognized quality and safety standards.

3. Multicriteria analysis methods: In projects with diverse requirements and conflicting criteria, multicriteria analysis methods can be useful for assigning weights and importance to each material property and obtaining an objective evaluation.

4. Specific tests and trials: In cases where the available data is insufficient, conducting specific tests and trials can be a way to obtain more precise information about the properties of materials under specific operating conditions.

The use of these tools and auxiliary resources can bring several benefits to the materials selection process. In addition to saving time and resources, these tools allow for a more precise and comprehensive analysis of available options, making the decision-making process more objective and data-driven. This reduces the possibility of inappropriate choices and increases the reliability and performance of the final product.

However, it is important to emphasize that the use of auxiliary tools and resources does not replace the experience and knowledge of the professionals involved in the materials selection process. The use of these tools should complement the judgment and expertise of engineers, ensuring a balanced and informed approach.

3.5 STAGE 5: DECISION MAKING AND JUSTIFICATION OF THE CHOICE

After analyzing and comparing the properties of the materials, a decision is made and the choice of the most suitable material for the project in question is justified. At this stage, engineers and professionals must consider all the information collected, the specific requirements of the project, the budgetary constraints, the tools and resources used to assist in the selection, and the client's expectations in order to make an informed and data-driven choice.

Decision-making involves carefully evaluating each material against the criteria and requirements established during the project needs identification phase. Each material property is weighted according to its relevance to the specific application, and options are objectively compared. It is important to remember that, in many cases, a compromise between different properties may be necessary to find the best overall solution for the project.

During the decision-making process, consulting experts and seeking the opinions of other stakeholders can be taken into consideration. Gathering different perspectives can enrich the analysis and provide additional insights, helping to make a more informed decision.

After making a decision, it is essential to justify the choice of the selected material. The justification must be based on concrete data and evidence, demonstrating how the chosen material meets the specific requirements of the project and offers the best solution for the application in question.

3.6 CONSIDERATIONS

The proposed methodology for material selection in mechanical design is structured in five interrelated stages, providing a systematic approach to assist engineers and designers in choosing the most suitable materials. However, it is crucial to recognize that the material selection process should not be viewed as a linear sequence, but rather as an iterative process. This means that, throughout the stages, it may be necessary to revisit previous phases as new information becomes available or new considerations arise.

This iterative nature allows for essential flexibility in decision-making. As data collection and analysis of material properties progress, there may be a need to redefine requirements or explore new options that were not initially considered. Furthermore, the feedback obtained during the analysis and comparison stages can lead to adjustments in selection criteria, ensuring that the decisions made are as informed and well-founded as possible.

The continuous interaction between the stages also contributes to a deeper understanding of the implications of each choice. For example, when considering the mechanical and thermal properties of a material, the need to review the operating conditions and, consequently, the design requirements may be revealed. This cyclical approach not only enriches the selection process but also ensures that the final solution meets all expectations in terms of performance, durability, and economic viability.

Therefore, applying this methodology requires an open and collaborative mindset, where engineers and designers are willing to revisit and adjust their decisions as needed, resulting in a final product that not only meets but exceeds the project requirements.

4. RESULTS AND DISCUSSION

The methodology developed for material selection in mechanical projects was based on a literature review that highlighted the importance of systematized processes to align material selection with the specific demands of each project. Among the most relevant findings, the review revealed that systematizing the process not only increases the accuracy of the choice but also allows for a more sustainable and economical approach, crucial for the development of reliable and efficient projects.

The results demonstrate that the developed methodology offers a clear and objective framework that allows for a comprehensive approach to the multiple aspects influencing material selection. The first stage, focused on identifying needs, is fundamental to ensuring that the selected materials meet the specific requirements of each application, while data collection and comparative analysis allow designers to consider a wide range of properties. The use of auxiliary tools, such as computer simulation (CAD/CAE), proves essential for increasing the accuracy of the analysis. These steps are crucial to answering the central research question, which seeks to ensure that material selection results in a project optimized in terms of performance and cost-effectiveness.

When compared with previous studies, such as those by Ashby (1993) and Sapuan (2010), it is observed that the proposed methodology shares common aspects with already established systematic approaches, such as the use of databases to facilitate the choice of materials. However, the developed methodology goes further by more specifically integrating the use of auxiliary tools, promoting an in-depth and interdisciplinary analysis that considers both technical and economic aspects. Unlike traditional methodologies, which are limited to a list of properties, this method offers a more holistic approach by incorporating the assessment of sustainability and environmental impact.

The results obtained corroborate the theories described in the literature, especially regarding Ashby's (1993) approach to material selection, which highlights the need for a rigorous and data-driven framework. The methodology developed is based on these theories by proposing a logical sequence of steps that facilitates the informed and optimized choice of materials . These results not only support existing theories but also provide a starting point for new discussions on the importance of sustainability and interdisciplinarity in the selection process.

The limitations of this study are related to the scope of the research and the availability of data. The analysis of material selection criteria was based on a literature review, which may not include the most recent innovations in the field of materials engineering. Furthermore, since the research was conducted in a specific context related to mechanical design, this may restrict the generalization of the results to other areas of engineering, as the conditions and requirements of projects vary between industries. This highlights the need for future studies that explore material selection in a wider range of applications.

5. CONCLUSION

The research conducted allowed for a deeper understanding of the material selection process in mechanical projects, highlighting the importance of a structured and rigorous methodology to meet technical, economic, and environmental requirements. The lessons learned show that a systematic approach is essential for more precise and efficient material choices. The proposed methodology reduces the margin of error in selection, contributes to the sustainability of projects, and promotes the development of products with high durability and optimized performance.

The objectives defined at the beginning of this work were fully achieved, since the developed methodology offers a practical and applicable tool for mechanical engineering professionals, facilitating decision-making and increasing the effectiveness of project development. It is concluded that the adoption of this methodology contributes significantly to improving the quality of final products, consolidating the role of material selection as an essential step in the success of engineering projects.

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