Designing Material Structures and Standards Considering Customer Requirements

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Abstract – Material standardization (the replacement of numerous components/ materials with a single component that provides all of the capabilities of the materials/components it replaces) is an essential purchasing department decision. For historical reasons, developing a standard has always included reaching a consensus among national and international groups. Voting determines whether or not the proposed standards will be accepted, and this is not geared for the consumer. Hence, including design principles into the process of creating material standards is beneficial. While looking at various material standards, it is not immediately clear how the customers' requirements have been met. This article will seek out the requirements of the consumer in terms of material standards and then look at the ways those needs have been addressed in four distinct norms. It would not zero in on any one material, but rather try to identify needs shared by designers across disciplines and media. As a result, there is no one standard that meets all of the criteria, and all of the standards only meet some of them.

Keywords – Materials Structure, Materials Standards, Sintered Materials, Spheroidal Graphite Cast Irons, Performance Specification, Performance Testing.

I. INTRODUCTION

In materials design and structuring, the final design phase requires the precise component material to be specified. If the product was tested using a specific material from a certain vendor throughout development, it would be helpful to include the material's components such as name, grade, and vendor on the blueprint. However, this kind of elaboration carries some danger, though. The maker may decide to no longer produce that grade, or the cost and availability may change. In this case, material criteria are crucial. The criteria or specification becomes fewer suppliers reliant when it refers to a material grade from a standard rather than a particular provider. It is important to remember that switching suppliers usually necessitates doing additional verification tests. Utilizing a common criterion will make it easier to locate a new supplier and substitute material. Many types of materials have different standard formats. Several grades with minimum (or maximum) values for a variety of material and other qualities are included in all material standards. For instance, if certain yield strength is required, the designer may consult the appropriate grade in the specification. The provider is the one accountable for making sure the strength standard is satisfied.

How these grades are verified and what attributes must be assessed might vary from standard to standard. To be "certified" implies to have one's material grade officially confirmed. A comprehensive material standard requires more than just a set of property tests. Further criteria are required since the material's qualities might change during manufacture or while in use. For instance, you may require that the material's microstructure be examined or that its chemical makeup fall within a specified range. For instance, the norm may stipulate that a certain grade requires a 90% martensitic structure. The material standards have been produced over a long period of time via the process of reaching agreement in Technical Committee (TC) meetings, which accounts for some of the variety. Organizations like as ISO and ASME, who create the standards, update them often. The resultant material standards are trade-offs that take into account the various interests of all parties involved. Production facilities have one agenda; testing facilities have another, and so on. The goal of any material standard, however, is to ensure that products can be reliably manufactured, used, and recycled by predicting how the material will behave at each stage of the process.

Reducing the number of tests needed, among other things, is a secondary concern. As a matter of fact, the designer is the standard's most important client. Given that, like any design challenge, developing material standards boils down to optimally satisfying customers' objectives within given limits. The first step in solving any design challenge is to have a firm grasp on what the client needs, then go on to brainstorming potential solutions. The ideas should be ranked, and the most promising ones should be fleshed out in depth for future study. Historically, national and international committees have been the primary forums for developing agreement on new standards. Voting determines whether the standards are accepted or rejected. The end-user experience is not prioritized. So, the process of creating material standards may benefit from borrowing ideas from the design industry. Researching various material standards might make it difficult to determine whether and how client needs have been met.

The purpose of this article is to identify the criteria for materials that customers want, and then to examine how those standards have been implemented in four distinct contexts. The goal is not to establish unique requirements for each material, but rather to identify universal needs shared by designers. This results in a range of degrees to which individual standards satisfy criteria, with no one standard providing a perfect fit. The remaining part of the article is arranged as follows: Section II focuses on providing an overview of materials structures and standards. Section III is about discussing customer requirements on a material standard. Section IV presents a discussion of examined materials standards, which Section V defines, the evaluation criteria for them. Lastly, Section VI presents concluding remarks as well as future research directions.

II. OVERVIEW OF MATERIALS STRUCTURES AND STANDARDS

Materials Structures

Sintered materials

Sintering, also known as frottage [1], is the process of producing a solid mass by compressing and heating it without causing it to melt. Sintering is a manufacturing method that is utilized with a wide variety of materials, including metals, ceramics, polymers, and more. The materials' atoms spread over the particles' borders, uniting them into one solid. As the sintering temperatures do not need to reach the melting point of the substrate, it is widely employed as the shaping method for materials with extraordinarily high melting temperatures such as tungsten and molybdenum. Powder metallurgy is the scientific study of sintering and other processes using metallurgical powders. Sintering occurs, for example, when ice cubes in a glass of water stick together due to the temperature differential between the water and the ice. The creation of a glacier from snowfall, or the crushing of loose snow into a ball to create a hard object, is both examples of sintering driven by pressure.

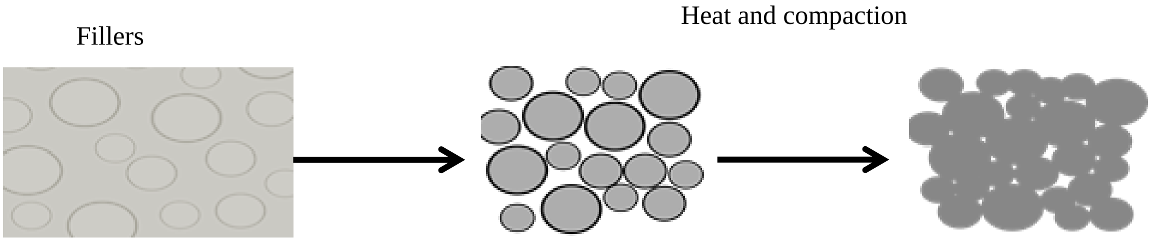

Fig 1. Heat and Compaction Process

The use of sintered materials is on the increase across the globe, especially for high-traffic areas like kitchen countertops, baths, and floors. Sintering is the process of transforming a powder into a solid by heating or compressing it below its melting point. Sintering is a thermal processing technique that compacts fine-grained materials like clay, feldspar, flint, and silica into a hard, ultra-compact substance (**Fig 1**). Before being rolled into the mold, these small grains are crushed, cleaned, and combined to get the proper consistency. Doing this step relieves pressure on the slab. The mixture is then baked in an oven to harden. The temperature at which a sintered material, like porcelain, is fired determines whether the resulting product is hard-paste, soft-paste, or bone china.

Sintering is effective if it decreases porosity and increases strength, electrical conductivity, transparency, and thermal conductivity, among other qualities. Sometimes, sintering is used to increase a material's strength while yet keeping its porous structure intact (e.g. in filters or catalysts, where gas absorbency is a priority). Powder surface removal throughout the fire process is driven by atomic diffusion, beginning with the creation of necks between powders and ending with the elimination of microscopic pores.

According to Gharleghi, Hung, Lin, and Liu [2], the substitution of solid-vapor interfaces reduces surface area, which in turn reduces the surface free energy and drives densification. A net reduction in free energy is achieved when new solid-solid contacts are formed. The variation in pressure and the dissimilarities in free energy across the curved surface have a microscopic impact on the process of material transfer. These effects get quite strong if the particle is very tiny (and has a high curvature). Ceramic technology relies heavily on the usage of fine-particle materials because the energy change is much greater at low radii of curvature. Strength and electric conductivity are two qualities that depend on the bond area to particle size ratio. During the sintering process, both the temperature and the starting grain size are carefully managed to achieve the targeted bond area. The vapour pressure is proportional to $(p0)^{1/3}$, and the particle radius is proportional to $(p0)^{2/3}$ in steady state.

The potential energy difference between the particle's neck and its surface provides the driving force for solid-state processes. This energy causes a material transfer to occur by the quickest route available, as opposed to using the volume of particles or the grain boundary between particles, which would reduce the particle count and ruin the pores. Samples with multiple holes of uniform size have the shortest border diffusion distance, making pore removal faster. Diffusion at the border and inside the lattice becomes more significant at the end of the procedure. As grain-boundary diffusion and volume diffusion are highly dependent on temperature, particle size, particle dispersion, material composition, and frequently other features of the sintering setting itself, temperature control is crucial to the sintering process.

Spheroidal graphite cast irons

Mechanical qualities are what set ductile iron apart from standard grey iron (elasticity, tensile strength, elongation...). **Fig. 2** shows a graphical representation of cast iron and ductile iron’s tensile strength against elongation characteristics. They occur because individual graphite atoms have a spherical shape. The amount of carbon present in the primary metal may be used to categorize finished ferrous goods: Carbon content ranges from 0% in iron to 0.1% in steel, 1.7% in cast or ductile iron, and 5% in steel. If the carbon content of the material is less than around 1.7%, it will solidify into the single-phase austenitic substance in which carbon is in solid solution. Whenever the carbon content rises over 1.7%, it becomes impractical to incorporate it entirely into the iron framework, and it precipitates out as a separate phase—typically iron carbide (Fe_3C) or graphite (pure C). Iron represents a multi-stage substance with a complicated structure, with ferrite (Fe) and pearlite ($Fe + Fe_3C$) being its most prevalent elements. Iron's structure, mechanical characteristics, and castability are all affected by even trace amounts of other elements. Iron is really a ternary alloy composed of iron, carbon, and silicon, with silicon playing a key role (often between 1 and 3 percent).

Several different types of Fe-C-Si alloys may be classified as "cast iron." The graphite condition is often used to divide them into subgroups, with further differentiation depending on the metal matrix structure (ferritic, pearlitic) [3]. Graphite in flake form is what gives so-called "grey irons" its metallurgical term, flake graphite irons (also known as lamellar graphite irons). Each flake has the potential to cause cracking by concentrating anomalous pressures in localized areas. As a result, metallurgists have experimented with altering the flake size and distribution in an effort to reduce or eliminate this impact. First, by using a centrifugal technique, flake graphite iron pipes (also known as "grey iron pipes") were significantly improved upon due to the creation of very fine graphite flakes. In 1948, spheroidal graphite iron, also known as ductile iron, was discovered as a result of research conducted in the United States and Great Britain. Rather of existing as flaky material, graphite now forms spherical precipitates. This means that fracture propagation lines can never form. By carefully adding a little quantity of magnesium to the desulfurized base iron, spheroidal graphite precipitation may be achieved. Pipes shouldn't have a Brinell hardness of more than 230 HB, whereas fittings and accessories may go up to 250 HB. In the heat-affected zone next to the weld, a greater Brinell hardness is acceptable for welded parts.

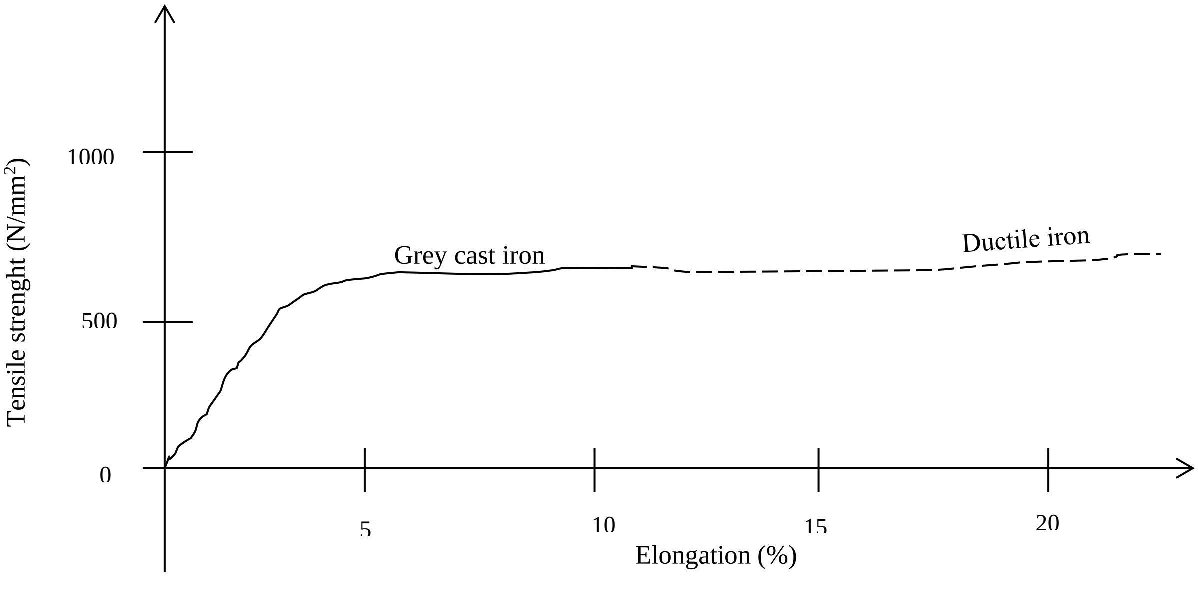

Fig 2. A graphical Representation of Tensile Strength against Elongation of Iron

Bolts, screws and studs

The most well-known types of fasteners are the bolt, screw, and stud [4]. Their primary use is in industrial production. Each one is uniquely shaped and designed to do a certain task. Here, we're attempting to differentiate between a screw, a stud, and a bolt. A screw is an inclined plane with a helical ridge that is wrapped around a nail. Simply said, it's a metal rod with a helical thread pattern running its length. It also features a turn that allows the screw to be turned with a screwdriver. The head of a screw is often shaped in a certain way. The size and form of the screw's head dictates the appropriateness of the tool for the job. Wrenches and screwdrivers are two of the most used tools. The bottom of the head, known as the shank, may be entirely or partly threaded, depending on the application. The helix shape of a screw thread is well suited to a cylindrical or conical surface. The peak of the ridge is known as the crest, while the base is referred to as a root. A thread's "pitch" represents the distance between its "crest" and the following thread's "crest." Screws are often utilized to secure the connection of materials that do not already have pre-drilled holes. In the manufacturing sector, dowel screws, concrete screws, mirror screws, and drywall screws are among the most frequent.

According to Zhu et al. [5], a screw's durability is determined by the width and spacing of its threads. Yet, the more threads there are, the more times the screw would have to be turned in order to secure it. Additionally, greater effort is needed to rotate the tool if there is more space between each thread. Screws have several uses and are thus ubiquitous. A bolt is a kind of externally threaded fastener designed to be inserted into correspondingly sized holes in the final product. Nuts are often used to secure or loosen bolts. Bolts differ from screws and studs in that their cross section is consistently round, and their threads have a spiral structure and a finer pitch. Bolts are superior to screws in terms of both strength and durability since their shanks are not tapered. Together, the nut and the bolt provide the function of tightening the application. Bolts like plow bolts, track bolts, and carriage bolts are often utilized. Bolts provide more dependability and durability than screws when joining pieces together. Uses for bolts include securing flange joints or other metal connections. In addition to their usage in machinery, bolts have found applications in the plumbing and electronics industries. The dependability of machinery and parts relies heavily on bolts.

Studs are threaded metal rods or shafts that may be used in several ways. The length of the rod often depends on the task at hand. A headless and externally threaded fastener is referred to as a stud. In other words, the stud is attached to the tapered section and the regular nut at the other end. Studs don't have the tightening heads that screws and bolts have. It is possible to install studs by hand without the need of any tools or external force. In contrast to smaller screws, and bolts, studs could penetrate fundamentally further into a threaded hold of interlinked application, approaching the area where no torque is being exerted. Torque readings are erroneous because screws and bolts are subjected to not only rotational force but also linear force. Since there is no rotating force on the studs, we obtain a more precise readout. There are three primary varieties of studs: completely threaded stud bolts, studs with two ends, and studs with a tap end.

Several types of studs are manufactured from different materials to meet certain operational needs. The studs' threads don't loosen up with time, so the clamping force they provide is consistent. Flanges are often attached using studs. Flange type and pressure class dictate the diameter of the holes in the flange and the length of the studs, which in turn determines the quality of the connection. Studs seal off machine holes to keep fluids inside. Heavy materials like turbines, tanks, cylinder heads, and gaskets may all be assembled with their help.

Cement

More than 10 distinct cements serve specialized building functions, each with its own unique chemical makeup and method of production. There are many different types of cement, including rapid-hardening cement (RHC) [6], low-heat cement (LHC) [7], sulphate-resistant cement (SRC) [8], high-alumina cement (HAC) [9], quick-setting cement (QSC) [10], blastfurnace slag cement (BFSC) [11], white cement (WC) [12], pozzolanic cement (PzC) [13], colored cement (CC) [14], hydro-phobic cement (HPC) [15] and air-entraining cement (AEC) [16]. Compared to Portland cement (PC), the lime concentration of RHC is higher. Having a high lime concentration serves the early-on goal of increasing strength. When the formwork for concrete has to be removed early, this is what is employed. As cement hardens because CaO absorbs CO_2 from the air to generate $CaCO_3$, adding more CaO causes more $CaCO_3$ to develop at an earlier stage, speeding up the hardening process.

The production of QSC involves fine grinding less gypsum and adding a tiny quantity of aluminum sulfate as an accelerator. When time is of the essence, such as in static or rushing waters, this cement is employed. C_3A, which is used to make gravity dams and other enormous concrete structures, has been lowered thanks to the Large Hadron Collider. By the time he's 13 weeks old, LHC already has a major heat-to-strength-of-hydration ratio of about 7. CaO: SiO_2 typically falls in the range of 0.80–1.5, whereas Al_2O_3 content is often under 10%. To make this amorphous material, we first grind the CaO, $Al2O_3$ and SiO_2, materials, then melt the mixture, satisfy the melt, and mill the satisfied matter. As alumina can absorb water, it can be hydrated, although reduced alumina has a lower hydration temperature. To prevent concrete from thermally cracking during the setting process, this is crucial in the building of big constructions. Ettringite, or hexacalcium aluminate trisulphate hy-drate [$(CaO)_6$ $(Al2O_3)$ (SO_3) $32H_2O$ C6ASH32], is formed when sulphate combines with the C3A and/or $Ca(OH)_2$ components of the hardened cement during a sulphate assault on concrete. In the availability of water, sulphate ions in cured concrete may react with $Ca(OH)_2$ or C_3A to create gypsum.

Ettringite and gypsum crystals, when they develop in voids in concrete, cause the paste to fracture as they expand. Sulfate assault is mostly determined by C_3A, the C_3S/C_2A ratio, and C4AF. In sites like culverts, canal linings, si-phons, and retaining walls, it is crucial to employ SRC since the integration of pozzolonic admixtures linke fly ash decreases the C_3A cement content. In order to become SRC ready, the C3A concentration must be kept below 6%. To make BFSC, clinkers are ground with around 60 percent slag. BFSC is used when cost-effectiveness is more important than aesthetics, and it has many of the same qualities as Portland cement. The bauxite and lime combination is melted and then ground with the clinker to produce HAC. Because of its high alumina content, this cement hardens quickly, taking just around 3.5 hours to set completely and 5 hours overall. Works that expose concrete to extreme heat, cold, and acidic conditions need for the usage of HAC. WC is manufactured from raw materials that are devoid of impurities like iron oxide and transition metal oxides including Cr, Cu, Mn, Ti and V.

The chroma impact is ranked as follows: Chromate (Cr_2O_3) > Manganese oxide (Mn_2O_3) > Ferric oxide (Fe_2O_3) > Vanadium oxide (V_2O_5) > Copper oxide (CuO) > Titanium dioxide (Ti_2O_3). For this reason, Mn3+, Fe3+ and Cr3+ should all be kept to a minimum while making white cement. Mn_2O_3, Fe_2O_3 and Cr_2O_3, levels in clinker are typically kept below 0.03%, 0.35%, and 0.003% correspondingly. Typically, Cr, Mn, and Fe may be found in inexpensive quarry raw materials. Fe_2O_3 is often found in the 0.3-1% range in lime stones and the 5-15% range in clays. Sand and Kaolin are utilized in place of other types of clays to create WC because Fe_2O_3 levels should be kept below 0.5%. Sand particles with a size of 45 m are abrasive, but they wear down the chrome-steel grinding mill employed in the processing of raw materials, preventing the introduction of those metals into the final product. Sand is typically processed in a separate ceramic grinding chamber to prevent chromium contamination during the grinding process. Because of its high price, WC is often only employed for decorative purposes, such as in terrazzo floors, facing panels, and precast curtain walls.

In contrast to WC, CCs are made by incorporating minerals colours into the mixture of cement. CCs are often employed in floor decoration. Red, yellow, and black are the primary colors obtained from iron oxides, along with a wide range of secondary colors. The pigments chrome oxide and cobalt aluminum oxide is the industry standards for green and blue. As a white pigment, TiO_2 is widely used. To make PzC, pozzolanic clinker is ground with Portlandcement. It is laid underwater to form bridges, piers, and dams, and it's utilized in maritime construction and sewage treatment plants. AEC is created by adding surfactant, such as permeation enhancers, hydrogen peroxide, and aluminum powder, to the clinkers while it is being ground. These surfactants include alkali salts of wood resin, synthesized alkylaryl sulphonate detergents, calcium lignosulfate obtained from the procedure of sulphite in paper manufacture, calcium salt of adhesives and other forms of proteins, as well as calcium salt of adhesives, including other forms of proteins. They may be added as a solid or liquid at a rate of 0.025 to 0.1 percent. AEC generates hard, small, distinct, noncoalescing air bubbles in the core of the concrete during mixing, with a size of 10-500 m.

As these bubbles are compressible, they help mitigate the strain caused by freezing. To make HpC, water-repellent compounds are added to the mix. They are tailored for usage in high-rainfall areas to stop the accumulation of moisture. Nonpolar compounds are affixed to HpC particles, often by the adsorption of fatty acids like oleic acid, stearic acid, etc. When adsorbed, the carboxylic acid groups of these surfactant molecules coordinate with surface cations, forming a stable three-dimensional structure that allows the nonpolar hydrocarbon chains to potentially stretch from particles. As with the lotus leaf, when a drop of water hits them, they roll off the hydrocarbon chains and remain as spheres. When water droplets hit the cement at an angle, they don't soak in and instead roll right off. These hydrophobic coatings protect against chloride and sulfate ion assaults, protecting concrete from degradation.

Materials Standards

Performance and prescriptive features are combined in modern material standards. The mechanical and physical qualities of the material are examples of performance aspects that are tailored according to the requirements of the designers. The purpose of the prescriptive aspects is to validate the outcome. One example is making sure the material's microstructure is as intended. The terms "prescriptive" and "performance" are most often heard in the construction industry. In this work, it will also refer to other categories of resources and hardware. Minimum property requirements, such as the maximum stress a material must sustain, are specified in all relevant standards. In order to verify that a material is of a given grade, these characteristics must be tested according to established protocols. These test protocols, including the amount of samples to test, etc., are detailed in the standards to which they correspond. Thus, with a high degree of confidence, we may say that the property's value exceeds the baseline requirement. Normative characteristics are those that must always be checked. There are several criteria where property values are not required to be examined. Their only purpose is to suggest a potential end result. They are known as instructive graphics.

Prescriptive specification

Instead than focusing on performance criteria, a prescriptive specification details the design and chemistry of the concrete mix processes and procedures. Prescriptive requirements might clash with the expected performance if they are not explicitly established in the project specifications. The minimum amount of cement, the score of cement, the limits on the quantity of supplementary cementitious materials, the optimum ratio of water to cement components (w/cm), the limits on the leveling of aggregate particles or the category of aggregate utilised, identifiers of admixture and mixtures, and so on are just some of the concrete mixture composition restrictions that may be mandated by the project. Compressive strength and other qualities may be assumed but not stated in the specification. These conditions are not always met because of limitations placed on the mixture's constituents. For each category of components, there is a corresponding link between the mixture's ratios, such cement ratio and w/cm ratio, and the resultant durability and strength attributes.

Prescriptive criteria for concrete composition, strength and cover

EN 1992-1-1 - Eurocode 2 establishes the requirements for the protection of structural elements made of reinforced concrete. The unpredictability of this variable in connection to the execution is also considered in line with NP ENV 13670-1. Eurocode 2 therefore provides the nominal cover cnom in addition to the minimal cover cmin and the duration of cover dur (mm). Drawings and specifications for a building project should be adjusted to account for any projected variance by using cnom as the base value. cnom = Cmin, dur + ΔCdev (1) where ΔCdev (mm) is the anticipated deviation which relies on the quality standards, and in the Portuguese example 10 mm was the established number notwithstanding the degree of quality control. In the case of a normally distributed concrete cover, the minimal concrete cover Cmin, dur may be understood as a fractile characteristic value of 5%, with Cdev = 1.645s. Given that the average nominal cover is 6 mm, the standard deviation is also 6 mm.

The Portuguese requirements may be found in the National Annex to the standard NP EN 206-1. Hence, the minimum conventional cover, including the minimal cover and its variation, and the requirements for the composition of fortified concrete members are all laid forth in this document. For a designed working life of fifty years (goal time) under environment exposure, taking construction class 4 into consideration, the restrictions given in [17] comprise the prescriptive technique. This standard allows for a designed working life of 100 years, with structural class 6, using the same permitted limitations of the concrete compositions and adding 10 mm to the 50 years cover. In addition to the required concrete depth, there are also maximum and minimum values for the water-to-cement ratio, cement quantity, cement type, and strength category.

Performance Specification

The requirements must be clearly stated in the performance specifications, as should the testing procedures and acceptance criteria which will be utilized to ensure compliance. Certain tests can be needed for prequalification, while others might be needed for actual employment. The performance criteria should be written in a manner that allows the contractor and producers to offer a mix in whatever way they deem suitable. To make sure the performance criteria are met, the contractor and manufacturer will work together to develop a mix design for the plastic concrete that accounts for factors like flow and set time during installation and finishing. Any restrictions on the materials or proportions that may be used in the concrete should also be avoided in performance standards. An alternative to prescriptive durability design is performance-based design and specification.

To account for the effects of building procedures and the efficacy of workmanship on the as-built structure's durability, the key durability-related characteristics should be assessed. Most performance-based standards, however, only cover the primary features to be assessed during the design phase or at the time of concrete delivery, and do not provide a means of determining whether or not the final structure or its parts are in fact compliant. Because of this, the authors argue, performance-based techniques can no longer be relied on to ensure that the built structure really satisfies its requirements. From authors in [18], an application's functionalities for hardened concrete are outlined in performance standards, which are "a collection of explicit, quantifiable, and enforced instructions." They stress the need of performance-based standards in defining the roles of the owner/designer, the concrete manufacturer, and the contractor. On the other side, the owner/designer bears the brunt of the danger while working with prescriptive requirements. When the concrete is specified and tested at the time of delivery, as well as again after installation and early hardening in the building, the risks and duties of the concrete supplier and the developer are clearly stated.

Performance Testing

Establishing appropriate performance limits and creating trustworthy test methodologies are essential parts of performance testing. The correct limit may be derived using service life models, such as when extrapolating a chloride permeability coefficient from the Life 365 simulation. In other cases, especially those where service life modeling are not well defined, the constraints that result from best judgment and experience must be modified or improved when newer, more accurate models become available. In addition, performance evaluations have many practical applications.

Pre-qualification mixes are used before construction begins, at which point the concrete producer conducts tests to demonstrate that the requisite concrete fulfills the performance limits; it is evident that only the 'prospective' material (in the context of the material's prospects to be durable) is proven in this situation. When it comes to quality control (QC) in the construction industry, performance testing can be put to two different uses: first, checks on concrete mixtures as procured or delivered prior to them being installed in the structure, analogous to the routine concrete strength tests done today; and second, checks on the finished product once it has been installed in the structure. Second, whether the real structure is verified with in-situ inspections or with laboratory testing of samples taken from the structure, the purpose is to establish the built-in consistency of the structure. By evaluating a structure in its natural environment, the correlation between test results and expected output is more direct.

In addition, even though all of these tests are meant to evaluate the same fundamental performance feature, the tests themselves may vary depending on their intended usage. Prequalification testing, such as measuring the diffusion coefficient, may be performed on "laboratory" concrete, while quality control testing, such as measuring the resistivity/conductivity, can be performed in situ. Several of the evaluations focus on the capacity to break through concrete (the permeability of concrete to liquids, gases, and ions under various transport conditions). Many types of performance-based testing procedures have also been created (Chapter 4 of the RILEM TC-230 PSC State-of-the-Art Report will cover this topic when it is released later this year) [19]. Deterioration modeling may not always be necessary for the deployment of a performance-based strategy, as is noted by RILEM TC-230 PSC. If the loss of mass during the performance test is below a particular amount, the concrete mix is deemed acceptable during the examination of freeze-thaw resistance. As there is no suitable model against which to integrate the outcome, long-term experience serves as the de facto 'criterion' against which test findings are evaluated.

III. CUSTOMER REQUIREMENTS ON A MATERIAL STANDARD

The anticipated application of the standard informs the client needs. Making a supplier-neutral material specification is the first step in developing a standard for any material. Every given grade of material should perform consistently from manufacturer to manufacturer. The qualities change as the materials are heated or cooled, or when they are exposed to harsh situations like those seen in service. The chemical make-up of the substance determines the nature of these effects. Free compositional choice by manufacturers might lead to unanticipated variations in performance across grades. A change in annealing temperature or a change in the way a component formed from the material behaves in use might be the consequence of an extra or missing ingredient. Either the chemical makeup of the reference material may be specified, or the microstructure of the final product can be inspected to ensure accuracy.

Having the ability to foresee impacts beyond only the materials' response to heat treatment makes the first choice preferable for designers. The microstructure may be inspected directly using a microscope, or indirectly by examining a structural attribute. Several phases of varying shape, size, and distribution make up a material's microstructure (grains, dendrites, precipitates, spherulites, pores, lamellae, etc.). Different phases may be identified by their optical or electron microscopical appearances, which reveal crystalline, semi-crystalline, or amorphous structures, respectively. Engineers may achieve a broad variety of qualities from processed materials by manipulating their microstructure in precise ways. Establishing connections between macroscopic features and occurrences at the microstructural scale is essential for understanding the material's behavior.

In addition to chemical composition and structure, atomic mobility and the existence of concentration gradients during processing have a significant impact on the resulting microstructures in materials. The energy expenditure involved in forming new interfaces is also a major factor in microstructure creation. There is a wide range of microstructures that may be achieved with appropriate heat treatments (quenching, annealing). They are often metastable at service temperatures due to their inhomogeneous composition. Heat-treatments coupled with mechanical processes like rolling have attained a very high degree of complexity in the case of metals and alloys, allowing for precise control of the microstructure.

Crystalline microstructures predominate during solidification. A few materials, however, due to their uneven molecular structure, are resistant to crystallization at high temperatures. The solid state structure of these materials resembles glass. Heterotactic vinyl polymers are one example of this. Glass, when it occurs, is always less stable than crystal, and its transparency is due to the absence of microstructure. Organic polymers' microstructure is largely determined by their chemical architecture. Crystallization is possible for most macromolecules with a regular molecular structure. Nevertheless, polymer materials seldom fully crystallize, and only semi-crystalline spherulites develop in the bulk. The process of powder sintering is often used to produce ceramics. Because of this, we can understand why porosity is often seen in materials of this kind at the microscopic level.

To prevent unexpected shifts in material behavior, the specification's allowable limits for the chemical composition must be carefully selected. Thus, it is important that the TC designing the standards understand their intended use. If the chemical composition is tightly specified, there is minimal opportunity for improvement in the material. A standard that focuses on improving customers' lives by giving them access to more features for the same or less money is preferable. It is crucial to have an active and responsive TC when new materials are created. If there are items that can't be processed via the current grades, then new grades should be created. When issues arise with the current grades, for example when consumers start using the materials in novel ways, an active TC might be of assistance. Standards may be revised to include countermeasures with prescriptive activities, such as hardness testing to get insight into the microstructure. When the TC gains awareness of frequently recurring pitfalls, it should submit new tests to add to the standard. If an issue cannot be fixed immediately, the standard should at least make note of the fact that it exists. This may be shared before a new problem is created with the norm, ideally through a website.

It is crucial that the TC provides written justification for the adjustments, including the nature of the issue and how the countermeasure is intended to address it. The standard will become unintelligible if it is not well documented. Customers are more likely to have faith in the standards if they are simple to grasp. Publication of the standard should be accompanied by an explanation of any changes made to it. The standard is probably used for screening purposes in the first stages of design. The designer must be aware of the material's anticipated characteristics. The data does not need to be very accurate, but it should be sufficient for doing feasibility analyses and making comparisons to other materials and procedures. Several attributes have illuminating values that may be derived from the standard. Screening against material standards is useful, but it is secondary to the specification process. Many online tools and specialized programs help with the screening process. The designer does not know in advance which features are crucial for the design to succeed. Everything revolves around the goals of the design.

Tensile and ultimate strengths, two of the most often encountered elastic characteristics, are typically provided. The designer may alternatively want information on fatigue strength in rotational bending or electrical conductivity. Properties crucial to the success of the design should be normative in the sense that they allow the customer to hold the supplier liable if the material fails to meet the requirement. The scope of the testing needed to verify minimum levels of all possible attributes is outside the scope of the standard. To get around this issue, components with comparable needs may be grouped together to establish categories of components that need similar material attributes to function well. These are the exact features that should be mandated by the standard for inspection. Because of this, the designer will have an easier time during the specification phase, as the crucial characteristics for a certain product type will not be left out. The aforementioned characterization of chemical composition is also crucial for attempting to forecast the intended usage of the materials. Before deciding on a range, it is useful to have some idea of the material's intended processing and service applications. It's also important to recognize that the standard can't cover every possible scenario. The designer may need to make special provisions for testing if certain conditions apply. Classes having a wide range of use, such as "material for structural components," are required, with the understanding that the designer might request more testing if necessary.

Here are given, in descending order of significance, the six criteria that should be applied to a good material standard. First, it is expected that materials of the same quality from different manufacturers would perform similarly. Second, there has to be a way to hold the provider to account if the product is subpar. Third, justifications for the standard's structure and any proposed modifications need to be made clear. Fourth, the specification made by the designer should be supported by the standard. Fifth, the standard must permit grade enhancements that boost customer value. In the first phases of design, the standard should be valuable, as well (screening). The standard deviation of the parameters stated must also be quantified. Due to the unconditional nature of this need, it does not rank higher. The next six requirements have a sliding scale of completeness. The last stipulation must be met in all circumstances. In this research, we look at Criteria 1-6 over four distinct norms. How successfully these criteria have been satisfied may be gauged from this. Finding assessment criteria for point 6 is more challenging and has not been investigated. Moreover, there is a tension between the need to permit enhancements and the need for the grades to exhibit consistent behavior. There's not much space for improvement since similar behavior has to be precisely specified. Further research is needed to determine which of the two is more crucial in order to create the ideal material standard. Instead, having two distinct grading scales could be the most workable solution.

IV. EXAMINED MATERIAL STANDARDS

Standardization Organization International (ISO) 5755:2001 [ISO 5755 2001] is a specification for carbon steel and alloy steel fasteners The standards ISO 898-1:2009 [ISO 898-1 2009], ISO 1083:2004 [ISO 1083 2004], and ASTM C1157/C1157M - 10 [C1157/C1157M-10 2010] for cement, spheroidal graphite castirons, and other building materials have all been studied. These standards represent just a subset of the many applicable to these areas. They include both unfinished materials and finished products. Distinctions become apparent when comparing the criteria. Although the cast iron and cement standards are almost entirely performance driven, the other two standards are more evenly split between prescriptive and performance requirements. An explanation of each criterion is provided first in the assessment.

Sintered materials

In ISO 5755, there are a lot of tables arranged by chemical composition and application. This International Standard specifies the chemical composition and the mechanical and physical qualities that sintered metal materials used for bearings and structural components must have. The attributes of powder metallurgical materials rely on their density, chemical composition, and manufacturing techniques. Sintered materials may not have the same qualities as wrought or cast materials, which might be used instead, even if they perform well in some applications. As a result, talking to prospective providers is suggested.

Each substance is given a unique identifier, such as "F-05C2-300," which designates it as copper-carbon steel with minimum tensile yield strength (YS) of 300MPa (Megapascals). Grades related to bearings may be found in 2 of 11 tables in ISO 5755. For structural components, ferrous materials are found in Tables 3 through 10 of ISO 5755, whereas non-ferrous elements are found in Table 11 of ISO 5755. The tables include both descriptive and normative characteristics. All grades need a chemical analysis of the powder. The components' indicated percentage values have a substantial margin of error. The tables include various details on the qualities that are normative and instructive. For bearing classes, the open porosity and radial crushing strength are usual. Informative numerical values are also supplied for a few more features. Tables 3–11in ISO 5755 provide the minimum allowable yield strength (YS) or ultimate tensile strength (UTS) of structural components. The qualities for which relevant values are supplied include the fatigue limit, hardness, and elongation. In the standard, the maximum permitted shrinkage after sintering is not included.

Spheroidal graphite cast irons

The spheroidal cast irons [20] (ISO 1083) are organized into grades in the same manner as sinter steels are. ISO 1083, JS 400, and U grade are all grades. Cast iron with ausferritic spheroidal graphite is denoted by the letters JS. The two numbers, 400 and 15, in the designation indicate that the material has minimum UTS of 400MPa and a minimum extension to fracture of 15%. The letter U indicates that this is a cast-on sample. Alternately, the initials RT and LT may be added to the designations to indicate that low temperature (LT) or room temperature (RT) impact resistance requirements must be met, respectively. Of note, the standard makes no mention of the iron's chemical make-up. While a sample chemical composition is provided, the final decision rests with the producer. The manufacturer must to demonstrate that the graphite is spheroidal and meets the requisite mechanical qualities to qualify a grade.

Bolts, screws and studs

Metric nuts, bolts, and studs have their own unique naming convention (ISO 898-1). The M (for metric) followed by the nominal size of a screw, such as "M8," is the standard notation. Screw material qualities are specified by the two-digit pair x.y, where x represents the ultimate tensile strength (UTS) of the material in hundreds of megapascals (MPa), and y is the factor by which this value must be multiplied to achieve the yield strength (YS). This multiplier is tenfold. Hence, 10.9 indicates 1000Mpa UTS and 10*0.9=900MPa YS. UTS and YS imply pressures of 800 and 640 MPa, respectively, for a Class 8.8. Just subsets of dimensions and classes have both tensile qualities examined. Minimum and maximum values for alloying components in the material's chemical composition must be verified.

The annealing temperature must also be within certain parameters. All screws need to have their thread surface roughness and hardness checked. Certain qualities are required, others are recommended, and some are impossible to check unless you know the exact screw class and size. Some of them include UTS, elongation, decarburized zone size, proof load, and a few more. For each dimension and class, the table indicates whether or not the inspection of that particular item is feasible, nonfeasible, or voluntary. The material's microstructure must also meet certain standards. All screws in classes 8.y and above must pass a structural inspection to ensure they are 90% martensitic. This new rule ensures that ductility is restricted, delaying the onset of YS relative to UTS.

Cement

Hydraulic cement is primarily governed by a performance-based ASTM standard (C1157/C1157M-10). There are six categories to choose from: All-purpose (GU), early strength (HE), sulphate resistance (MS), sulphate resistance (HS), heat of hydration (MH), and heat of hydration (LH) are the four categories. Unlike the other three standards, there is not a division into different strength classes here; rather, a single set of criteria applies to each kind. The norm specifies procedures for verifying compliance with all prerequisites. Compressive strength is measured at 1, 3, 7, and 28 days for each of the six categories, and it must be above minimal values in all cases. The dimensions must be consistent, with a maximum allowable shrinkage specified. The cement must meet certain criteria, which vary depending on the use (HE, MS and so on). For instance, MH and LH types benefit most from the heat of hydration. Further conditions for low reactivity (option R) might be specified if desired. There are measurable qualities in the standard for which there is no upper bound. Fineness, as measured by the percentage retained on a 45 m sieve, air content, and dry shrinkage are the aforementioned characteristics.

V. EVALUATION CRITERIA

Certain criteria are required to evaluate the degree to which the previously defined client needs are satisfied. Each benchmark in **Table 1** below has been evaluated according to these criteria. The chemical composition is either stated or the microstructure is confirmed in some way to ensure that the grades exhibit identical behavior (requirement 1). The number of normative qualities is used to assess Compliance with Requirement 2 (Accountability). All normative qualities are specified according to requirement 3 (deviation). For the informative qualities, not one of the standards provides an anticipated variance. Two sub-requirements, motivated structure and motivated adjustments, make up requirement 4 (motivation).

Table 1. Evaluation Criteria for the Examined Standards

	C1157/C1157M-10 (Cement)	ISO898-1 (Fasteners)	ISO5755 (Sinter)	ISO1083 (Cast Iron)
Informative elements	x	x	√	√
Dedicated classes	√	√	√	x
Changes categorized	√(f)	x	x	x
Structure of standards	x	x	x	x
Motivation	-	-	-	-
Deviation specified	√	√	√	√
Number of normative elements	12 (d,c)	10 (c)	2 (b)	4
Microstructures	x	√	x	√ (a)
Chemical composition	x	√	√	x
Similarity	-	-	-	-

Graphite spheres are required in (a) explanatory paragraph about preponderant cellular architecture. (b) Each table has a different set of normative qualities. (c) The range is from 2 to 10 depending on the strength class (d) four of the twelve characteristics are discretionary. (e) None of the limit values apply to three of the characteristics. The certificate includes measurable and declared property information. (f) Detailed notes on how this problem differs from the last one are provided.

VI. CONCLUSIONS AND FUTURE RESEARCH

The material's actual chemical composition is typically overlooked by designers. When it comes to materials, the golden rule should be to avoid adding additional requirements, since this hinders the continual development of current classes. Only when issues are foreseen (such as when trying to maximize or minimize in the components) can the chemical composition be provided. The sinter standard has fewer normative features than the other standards. Provider accountability for maintaining normative features and limiting variation highlights the value of a rich set of standards. More normative qualities means more testing is needed to validate the results. In that case, it would be ideal if the TC began classifying typical component kinds with comparable customer requirements. Then, testing would be limited to only the attributes that matter for that component type.

Without diminishing the standard's utility, this would aid designers in creating requirements and reduce the number of tests required. Several types of powder metallurgical parts have been identified. It is worth noting that the differences between issues of the American cement standard are explicitly accounted for in the latest edition of the standard. Understanding how the standard has evolved through time is helpful for the design process. None of the standards provide any in-depth justification for the structure beyond a cursory overview. Taking into account the intended purpose of the various parts is highly suggested. The designer's trust in the standard and openness to adopting it for material specification would both benefit from this. Two of the norms outline what kinds of information should be provided. As was previously mentioned, doing such screenings is no longer necessary. Instead, focus on the standard's requirements in the form of detailed specifications. By the use of material databases, material providers may provide information on the standard grades' performance. Only assured levels should be used in the benchmark.

Due to the fact that each material exhibits its own unique behavior, it is very unlikely that a single framework will be discovered that can be used to categorize all materials. Certain materials, for instance, need a more stringent specification because they are more vulnerable to changes in chemical composition. In future, it may be feasible to establish a standard that best meets the demands of the designers for certain categories of materials. Methods for evaluating the requirements, such as quality function for deployment, may be used to determine the best structure for such a standard. It is possible that the designer will find that the client requirements are so varied that the standard has to be broken up into sections, each with its own method of verifying the grades.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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References

[1]. P. Golmohammadi, F. Saljooghi, A. Bahmani, N. Parvin, and B. Nayebi, "On the synthesis and sintering behavior of a novel Mg-Ca alloy, Part I: Mechanical alloying," Synth. Sinter., vol. 2, no. 3, 2022.

[2]. A. Gharleghi, P.-C. Hung, F.-H. Lin, and C.-J. Liu, "Enhanced ZT of InxCo4Sb12-InSb nanocomposites fabricated by hydrothermal synthesis combined with solid-vapor reaction: A signature of phonon-glass and electron-crystal materials," ACS Appl. Mater. Interfaces, vol. 8, no. 51, pp. 35123–35131, 2016.

[3]. L.-Q. Huang and Q. Huang, "High-strength Ti–BN composites with core-shell structured matrix and network-woven structured TiB nanowires," Trans. Nonferrous Met. Soc. China, vol. 32, no. 4, pp. 1169–1177, 2022.

[4]. D. Zhang, L. Shen, X. Zhu, S. Zhang, M. Gong, and Y. Gao, "Comparative study on connection properties of shear bolt and screw of thin cross-laminated timber panel," Bioresources, vol. 18, no. 1, pp. 827–843, 2022.

[5]. Y. Zhu et al., "Finite element analysis of screw fixation durability under multiple boundary and loading conditions for a custom pelvic implant," Med. Eng. Phys., vol. 111, no. 103930, p. 103930, 2023.

[6]. I. Kirakevych et al., "Modification of cementitious matrix of Rapid-Hardening High-Performance Concretes," Theory build. pract., vol. 2021, no. 1, pp. 79–84, 2021.

[7]. J. Xin et al., "Exploring the effect of low-heat cement on early-age thermal cracking resistance of roller-compacted concrete," J. Mater. Res. Technol., vol. 21, pp. 4439–4451, 2022.

[8]. V. Petropavlovskaya, "Influence of acid-activated micro-dispersed additive on the properties of cement sulphate-resistant compositions," in Materials Research Proceedings, 2022.

[9]. J.-S. Huang, J.-Y. Lin, and M.-J. Jang, "Stress relaxation of foamed high-alumina cement paste," Cem. Concr. Res., vol. 35, no. 8, pp. 1503–1509, 2005.

[10]. H. Wang et al., "Grouting reinforcement mechanism and experimental study of cement quick-setting slurry infiltration," IOP Conf. Ser. Earth Environ. Sci., vol. 81, p. 012025, 2017.

[11]. Z. Osmanovic, N. Haračić, and J. Zelić, "Properties of blastfurnace cements (CEM III/A, B, C) based on Portland cement clinker, blastfurnace slag and cement kiln dusts," Cem. Concr. Compos., vol. 91, pp. 189–197, 2018.

[12]. Z. Wang, L. Huang, P. Lian, and S. Huang, "Effect of flotation phosphorus tailings on the microstructure and compressive strength of white Portland cement," Adv. Cem. Res., vol. 34, no. 7, pp. 283–291, 2022.

[13]. A. V. Korkmaz and H. F. Kayıran, "Investigation of mechanical activation effect on high-volume natural pozzolanic cements," Open Chem., vol. 20, no. 1, pp. 1029–1044, 2022.

[14]. Y. Jin et al., “Rheological properties, shape stability and compressive strength of 3D printed colored cement composites modified by needle-like pigment,” Addit. Manuf., vol. 57, no. 102965, p. 102965, 2022.

[15]. W. Dong, W. Li, Y. Guo, F. Qu, K. Wang, and D. Sheng, “Piezoresistive performance of hydrophobic cement-based sensors under moisture and chloride-rich environments,” Cem. Concr. Compos., vol. 126, no. 104379, p. 104379, 2022.

[16]. S. Chatterji, “Freezing of air-entrained cement-based materials and specific actions of air-entraining agents,” Cem. Concr. Compos., vol. 25, no. 7, pp. 759–765, 2003.

[17]. A. K. Sharma, D. M. Sharma, N. Purohit, S. K. Rout, and S. A. Sharma, “Analytics Techniques: Descriptive Analytics, Predictive Analytics, and Prescriptive Analytics,” in Decision Intelligence Analytics and the Implementation of Strategic Business Management, Cham: Springer International Publishing, 2022, pp. 1–14.

[18]. Sub-Committee on Test Methods and S, “Jsce standards ‘test method for leaching of trace elements from hardened concrete,’” Doboku Gakkai Ronbunshuu E, vol. 62, no. 3, pp. 587–591, 2006.

[19]. Rilem.net. [Online]. Available: https://www.rilem.net/groupe/230-psc-performance-based-specifications-and-control-of-concrete-durability-244v. [Accessed: 08-Apr-2023].

[20]. M. J. Castro-Román, J. Lacaze, A. Regordosa, J. Sertucha, and R. del Campo-Castro, “Revisiting thermal analysis of hypereutectic spheroidal graphite cast irons,” Metall. Mater. Trans. A, vol. 51, no. 12, pp. 6373–6386, 2020.