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The Role of Andalusite in Enhancing the Physical & Mechanical Properties of Refractory Bricks: A Systematic Literature Review

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ABSTRACT:
This study aims to systematically examine the role of andalusite in improving the physical and mechanical properties of alumina-based refractory bricks through the Systematic Literature Review (SLR) approach to the scientific literature published in 2016–2025. This study focuses on the impact of andalusite on cold compressive strength, thermal shock resistance, porosity, sintered density, and dimensional stability at high temperatures. The bibliometric method using the VOSviewer software was used to map research trends and the relevance of keywords such as "temperature," "mullite formation," and "shock resistance." The analysis showed that andalusite plays an important role in forming secondary mullite during heating, which directly impacts the improvement of the microstructure and thermomechanical resistance of the material. Andalusite also acts as a protector against slag penetration and chemical corrosion, making it a strategic additive in modern refractory brick formulations. Some studies have shown that andalusite pre-calcination can improve fracture modulus and volume stability and minimize sintering energy requirements. Using andalusite is also considered environmentally friendly because it can replace expensive materials such as tabular alumina or zirconia and be used from domestic sources. These findings significantly contribute to the development of material designs that are adaptive to extreme conditions, efficient in energy consumption, and potentially reduce maintenance costs in the long term. The conclusions of this study confirm that the use of andalusite in alumina bricks offers structural advantages, energy efficiency, and long-term sustainability, as well as opens up further research opportunities for developing high-performance fire-retardant materials in extreme temperature industries.

Keywords: Andalusite, Refractory Brick, Alumina, Secondary Mullite, Thermal Shock, Sintering, Dimensional Stability

INTRODUCTION

In the modern industrial era, where energy efficiency and resistance to extreme conditions are increasingly demanded, refractory materials play a crucial role in high-pressure thermal systems such as smelting furnaces, cement kilns, steel mills, and heat plants (Biswas & Sarkar, 2020). Among the various types of refractories, alumina-based ($Al2O3Al2O3$) refractory stones are renowned for their high resistance to elevated temperatures, wear, and chemical attack, making them a preferred choice in heavy industrial applications. However, challenges still persist in optimizing these materials' physical and mechanical properties. One continually researched approach in recent years is the incorporation of natural minerals such as *andalusite* to enhance the performance of alumina bricks.

Andalusite is an alumino-silicate mineral ($Al2SiO5Al2SiO5$) with the unique ability to transform into *mullite* and amorphous silica at high temperatures without passing through a liquid phase. This transformation occurs via a solid-state mechanism, providing significant advantages in terms of volume stability, thermal shock resistance, and the development of a *mullite* microstructure that strengthens grain bonding. *Mullite* is a ceramic phase prized for its high mechanical strength, resistance to extreme temperatures, and excellent insulation properties. When *andalusite* is used as an additive in alumina-based refractory bricks, it increases microstructural cohesion, decreases open porosity, and boosts compressive strength as well as resistance to abrasion and chemical corrosion.

Several recent scientific studies have confirmed the positive role of *andalusite* in alumina refractory systems. Research by Zhao et al. (2024) demonstrates that adding *andalusite* to corundum refractory can inhibit alkali vapor permeation, improve corrosion resistance, and extend material lifespan in environments exposed to aggressive alkali metals. The study also notes that secondary *mullites* formed from *andalusite* enhance resistance to ion diffusion and the permeation of harmful gases common in industrial processes. Meanwhile, Liu et al. (2022) showed that combining *andalusite* and *kyanite* in ultra-low-cement bauxite-corundum bricks significantly improves cold compressive strength and modulus of elasticity while maintaining slag resistance and reducing open porosity.

Additionally, research by Xu et al. (2022) provides evidence that cement content in castables can be optimized by incorporating *andalusite* to enhance high-temperature performance. This improvement is directly related to the ability of *andalusite* to generate microcrystalline *mullites* that act as reinforcement bridges within the alumina matrix, enhance thermomechanical resistance, and prevent crack propagation at high temperatures. Wu et al. (2022) further highlight that the combination of *andalusite* and carbon black in the Al2O3–SiC–CAl2O3–SiC–C system not only strengthens grain bonds but also improves resistance to silica-magnesium slag penetration, thereby markedly extending the material's lifespan.

Equally important, the sustainability aspect in developing fire-resistant materials has gained attention. According to some sources, *andalusite* is considered an economical and environmentally friendly alternative to expensive materials like tabular alumina or zirconia, while also lowering the energy consumption required for sintering. Moreover, the availability of local *andalusite* in several mining regions supports potential industrialization based on domestic resources. Yuan et al. (2024) investigated the use of *andalusite* with waste materials such as carbon-rich coal gangues and found that *andalusite* facilitates the formation of *mullite* and SiC nanowhiskers structures, thereby strengthening alumina ceramics in situ with promising results.

From a practical point of view, it is crucial to recognize that refractory performance depends not just on the choice of materials but also on fabrication methods, grain size, particle distribution, and sintering processes. In this context, systematically evaluating the overall influence of *andalusite* on various refractory parameters becomes highly relevant. Thus, a systematic literature review (SLR) is needed to synthesize scientific findings published in the past five years and to understand the mechanisms, benefits, and limitations of using *andalusite* in alumina-based refractory bricks.

In conclusion, integrating *andalusite* into alumina refractory systems paves the way for developing materials that are not only mechanically robust and thermally stable but also sustainable and cost-effective. This strategy aligns with the vision of Industry 4.0 and green manufacturing, which emphasizes resource efficiency, waste reduction, and the creation of multifunctional materials resilient and adaptive to complex operational environments.

RESEARCH METHODS

This study uses a Systematic Literature Review (SLR) approach supported by bibliometric analysis to explore in depth the role of *andalusite* in improving the physical and mechanical properties of alumina-based refractory brick materials. This SLR approach was chosen to compile and evaluate the results of previous research in a systematic, objective, and structured manner using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol. The aim is to identify research trends, relationships between variables, and gaps in the literature related to the use of *andalusite* in refractory systems.

The literature review was conducted by searching reputable scientific databases (Scopus, ScienceDirect, Web of Science) for peer-reviewed English articles published between 2016 and 2025 that specifically examine *andalusite* use in alumina-based refractory bricks, focusing on quantitative and qualitative measurements of physical properties (density, porosity, thermal conductivity) and mechanical properties (compressive strength, abrasion resistance, thermal shock resistance). VOSviewer software facilitated bibliometric analysis by mapping relationships between key concepts such as "*andalusite* transformation," "mulliteization," and "thermal shock resistance," while the PRISMA framework guided the systematic identification, screening, eligibility assessment, and inclusion process, ultimately categorizing selected studies thematically to analyze *andalusite*'s effects on microstructural properties, thermomechanical performance enhancements, and industrial applications in metal smelting, cement kilns, and chemical plants.

Through this method, this study is expected to provide a comprehensive understanding of how the role of *andalusite* as an additive can improve the performance of alumina refractory materials and identify further research opportunities in developing efficient, environmentally friendly, and high-performance refractory materials.

RESULT AND DISCUSSION

This study aims to systematically and comprehensively present the role of andalusite in improving the physical and mechanical properties of alumina-based refractory bricks based on the Systematic Literature Review (SLR) approach to scientific articles published between 2016 and 2025. The primary focus of this study was to identify how the addition of andalusite impacts important parameters such as cold compressive strength, resistance to thermal shock, porosity, sintered density, and volume stability of alumina refractory bricks.

VOSviewer software is used to perform bibliometric analysis as an analysis supporter. This tool visualizes the relationships between topics, keywords, and the contributions of authors and research institutions in the relevant literature. By mapping terms such as andalusite, mullite formation, high-temperature performance, and alumina refractory bricks, the visualization results from VOSviewer provide an overview of the dominant knowledge structure and research focus that has developed in the last five years on this topic.

The results of the visualization of the VOSviewer application are as follows:

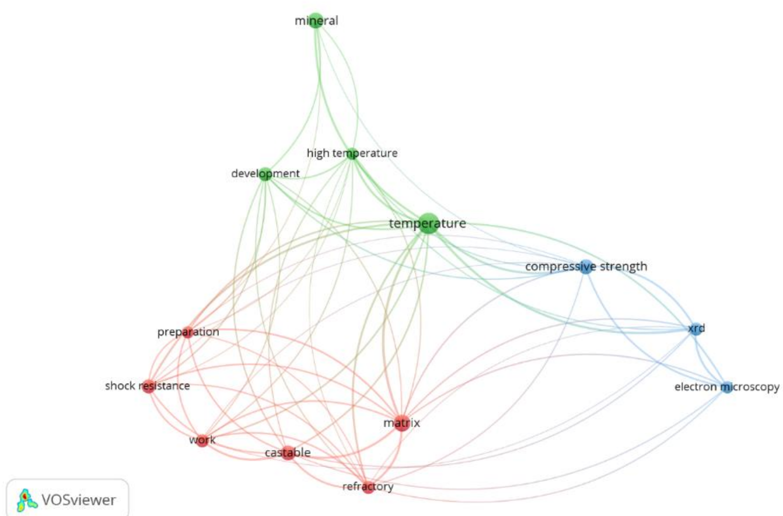

Figure 1. Network Visualization

Figure 1 presents a network visualization of the results of bibliometric analysis using the VOSviewer software. This network represents the relationship and linkage between important keywords in the literature that discuss the role of andalusite in improving the physical and mechanical properties of alumina-based refractory bricks. This network comprises several color clusters that signify clusters of keywords that often appear together and form focused topics in the research.

Green clusters dominate the top of the visualization, displaying keywords such as minerals, high temperature, development, and temperature. This cluster reflects the research focus on the thermal properties and high-temperature characteristics of refractory minerals, particularly how andalusite and other minerals play a role in developing heat-resistant materials. The word temperature is the central node that connects almost all topics because it is a key variable in the performance test of alumina-based refractory bricks.

On the other hand, red clusters are concentrated at the bottom of the network and contain terms such as castable, refractory, matrix, preparation, shock resistance, and work. This cluster emphasizes aspects of material engineering, such as the preparation process, material matrix system, and thermal shock resistance testing, which are the leading performance indicators of refractory bricks. The terms castable and matrix specifically indicate that much research focuses on monolithic materials and the influence of microstructures on material strength.

Meanwhile, the blue cluster on the right depicts the technical dimension and scientific characterization. Keywords such as compressive strength, XRD, and electron microscopy indicate the primary methods for evaluating materials' physical properties and microstructure. XRD (X-ray diffraction) and electron microscopy are essential techniques for crystalline phase identification and microstructure analysis, which are directly related to the final performance of andalusite-based refractory bricks.

The relationship between these three clusters indicates that the study of the role of andalusite cannot be separated from a multidisciplinary approach involving mineral characterization, material structure engineering, and comprehensive thermal and mechanical performance testing. This visualization also confirms that topics such as shock resistance, compressive strength, and matrix design are closely related to temperature as a central variable in almost all articles analyzed.

Thus, this network visualization shows a conceptual map of the latest research that illustrates that andalusite plays an important role as a material to improve the quality of alumina-based refractory bricks, both in terms of microstructure, mechanical strength, and resistance to extreme temperatures.

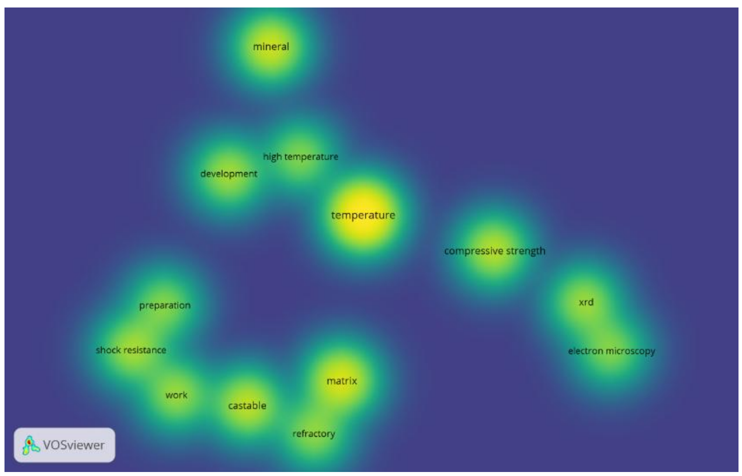

Figure 2. Density Visualization

Figure 2 presents the density visualization results from a bibliometric analysis using the VOSviewer software. This software displays the density of keyword occurrences in the literature related to the role of andalusite in improving the physical and mechanical properties of alumina-based refractory bricks. The colors in this visualization indicate the frequency of occurrence of a particular term in the corpus of literature: bright yellow indicates very high frequency, green indicates medium frequency, and dark blue indicates low frequency.

From this visualization, the keyword "temperature" emerged as the center point with the highest intensity (bright yellow), indicating that temperature is the primary variable in studying the performance of alumina-based refractory bricks with the addition of andalusite. This term is closely related to various aspects, such as the sintering process, the formation of the mullet phase, and the high-temperature performance test at the core of evaluating refractory materials.

Some other terms that also denote high density include “mineral,” “high temperature,” “development,” and “matrix.” The word “mineral” indicates the importance of andalusite’s characteristics as a natural mineral-based raw material. In contrast, “high temperature” and “development” focus on developing new formulations that can withstand extreme thermal environments. The terms “matrix” and “castable” indicate that much of the literature discusses a monolithic material system in which andalusite is incorporated as part of the microstructure of the alumina matrix.

In addition, terms such as “compressive strength,” “shock resistance,” and “preparation” appear at moderate densities, suggesting that the measurement of mechanical properties and resistance to loads and thermal shock is a central theme often studied in the literature. Meanwhile, the terms “xrd” and "electron microscopy" emerged with lower but still significant densities, reflecting the use of advanced characterization techniques in identifying the crystalline structure and micromorphology of the material being tested.

Overall, this density visualization illustrates that the primary focus of research in the last five years has rested on the relationship between high-temperature behavior and the influence of andalusite minerals on the strength and structure of alumina-based refractory bricks. This image clarifies that thermal aspects, mechanical properties, and microscopic characterization are the most dominant elements in scientific discussion in this field. Therefore, the results of this visualization are beneficial to direct thematic mapping and the preparation of conceptual frameworks in systematic studies.

Table 1. Comparison of Research Results with the Same Research Focus

Liu et al. (2022), Xu et al. (2022), Wu et al. (2022), Zhao et al. (2024), Yuan et al. (2024), Weinberg et al. (2021), Tang et al. (2021), Vlček et al. (2023), Moehmel et al. (2016), Choi et al. (2024)

Research Focus	**Main Methods/Parameters**	**Main Materials**
Andalusite and kyanite to castable thermomechanical properties	Microstructure test, slag resistance, compressive strength	Andalusite, kyanite, bauxite-corundum
Andalusite improves the dimensional stability of low cement castables	SEM, thermal testing	Andalusite, alumina
Effects of andalusite in the Al_2O_3–SiC–C system	Slag corrosion test, thermal testing	Andalusit, Al_2O_3–SiC–C
Penetration of alkaline ions in the corundum system	Ion diffusion test, SEM-EDS	Andalusite, corundum
Andalusite as an active component of SiC nanowhisker forming	Reactive synthesis, microstructure analysis	Andalusite, industrial waste
High-temperature oxide composition optimization	Simulation of thermodynamics, microstructures	Andalusit, TiO_2, P_2O_5, zircon
Andalusite precalcination and its effect on thermal shock	Fracture modulus test, thermal resistance, dilatometry	Andalusite, mullite-corundum

Research Focus	Main Methods/Parameters	Main Materials
Andalusite resistance to biomass corrosion	Crucible test, SEM-EDS, XRF	Andalusite, biomass ash
Evaluation of the performance of andalusite raw materials based on purity	SEM, dilatometry, RuL, CiC	Andalusit
Effect of hydrogen atmosphere on refractory bricks	Atmosphere reduction, SEM, color, strength	Andalusite, chamotte, clay

Table 1 compares ten studies with a similar focus, namely the use of andalusite in improving the properties of fire-resistant materials in castables and refractory bricks. Liu et al. (2022) and Xu et al. (2022) examined the contribution of andalusite and kyanite to the thermomechanical properties and dimensional stability of bauxite-corundum and alumina-based castables with low cement content. Both utilize microstructure analysis and thermal testing methods to demonstrate the role of mullite in strengthening bonds between aggregates and improving resistance to thermal shock.

Meanwhile, Wu et al. (2022) and Zhao et al. (2024) explored the resistance of andalusite to slag corrosion and alkaline ion penetration in Al_2O_3–SiC–C and corundum based systems, relying on corrosion assays and SEM-EDS analysis. The research of Yuan et al. (2024) is more innovative, making andalusite an active ingredient in forming SiC nanowhiskers for industrial waste-based ceramic applications. Meanwhile, Weinberg et al. (2021) focus on thermodynamic simulations to optimize oxide compositions (including TiO_2 and P_2O_5) in andalusite-based refractory systems.

The research of Tang et al. (2021) highlights the importance of the andalusite pre-calcination process in improving the stability of fracture volume and modulus in mullite-corundum materials, with dilatometry and thermal shock testing as the primary methods. In the context of an aggressive environment, Vlček et al. (2023) assessed the resistance of andalusite to corrosion by biomass ash using crucible test methods and mineral characterization. Moehmel et al. (2016) added an important point of view regarding the evaluation of the performance of various types of andalucite raw materials based on their purity level and their impact on the properties of Refractoriness under Load (RuL) and Creep in Compression (CiC). Finally, Choi et al. (2024) tested the behavior of andalusite in a reductive atmosphere (hydrogen), emphasizing the effect of reduction on the mechanical strength and discoloration of refractory bricks.

Some studies include Boersma et al. (2023) if discussed in detail. Investigating the most suitable flame retardant coating of different types or grades of products provided by various suppliers for hazardous waste incineration rotary furnaces is not an easy job, especially to achieve a service life of 23 months. Industrial-scale testing is time-consuming, i.e., only one or two new products can be tested annually or every two years. Crucible testing is a quick way to assess a product's suitability with a particular slag. However, classical visual observations to determine slag penetration zones are often inconclusive when materials from the same group are tested and can sometimes be misleading. This study conducted crucible tests on 10 commercial chromium-corundum bricks from various sources. After a detailed analysis using SEM (Scanning Electron Microscopy) and EDS (Energy Dispersive X-ray spectroscopy), an exact quantitative value was obtained for each sample's width of the corrosion zone. A dimensionless parameter called the Wear ratio was introduced as a quantitative criterion for characterizing the corrosion resistance of refractory materials. Using this Wear ratio, a correlation with chromium concentration (Cr_2O_3) was found. The quantitative results obtained through this approach align with field observations in real industrial-scale tests.

Bayoumi et al. (2022). Explains the thermomechanical properties of refractory castables, which are greatly influenced by their rheology and directly determine how they are applied in various industrial conditions. Dilatant behavior occurs in concentrated suspensions when there is an increased relationship between shear strain and viscosity. However, on the contrary, the shear-thinning character arises when the viscosity decreases as the voltage applied increases. This viscosity can be reduced through a uniform distribution of particles with a large average size, especially when using spherical or cube-like particles so that frictional forces between particles can be minimized. The fine matrix in a castable system plays an important role in regulating the transition points of formation between aggregates (Maximum Packing Threshold / MPT). However, viscosity becomes crucial when the fine components are too excessive. Submicron-scale particles tend to clump (agglomeration), but this can be controlled by adding the right amount of dispersant agents, which can regulate the forces between the surfaces of the particles. Considering many parameters, fireproof castables can be engineered to achieve the desired degree of smooth flow (Flowability). However, the optimization of these flow properties must be balanced with other variables that affect the strength and durability of the material as a whole so as not to compromise the structural stability and performance of the castable finish under high-temperature working conditions.

Nzeh et al. (2023). His research is focused on using magnetic and electrostatic field-based physical processing techniques and their application in the beneficiation and recovery of heavy minerals. This approach is expected to be an effective tool to reduce the process stages and complexity of extraction at the downstream stage, such as dissolution and hydrometallurgical processes, in processing these heavy minerals. Magnetic and electrostatic techniques in Beneficiation (quality improvement) heavy minerals (Heavy Minerals or HMs) have been systematically reviewed and discussed, with concise descriptions and simplified comparisons. Based on the published literature, it is clear that there is a high demand for the use of simple, cost-effective, and environmentally friendly physical beneficiation pathways to concentrate certain types of heavy minerals. This includes HM particles that are ferromagnetic, paramagnetic, diamagnetic, conductive, and non-conductive. On this basis, it should be noted that the choice of physical beneficiation technique for heavy minerals is highly dependent on the mineralogy, chemical composition, particle shape, particle size distribution (PSD), and the physicochemical properties of the mineral. Both magnetic and electrostatic concentrations greatly influence concentrating and increasing HM levels, thus facilitating simpler advanced extraction processes, both pyrometallurgical and hydrometallurgical. However, the performance efficiency of magnetic and electrostatic concentrators is highly dependent on certain process conditions, such as the strength of the magnetic field or electrostatic field, the response or level of sensitivity of the mineral to the magnetic field or electrical conductivity, the distribution of minerals, the process variables and the tool, the processing capacity, and the characteristics of the magnetic/electrostatic field distribution possessed by the HM particles.

In a study conducted by Liu et al. (2022), an investigation was conducted on the effect of the addition of andalusite and kyanite on the microstructural and thermomechanical properties of bauxite-corundum-based ultralow-cement castables. The study showed that andalusite significantly improved the cohesiveness of internal structures by forming secondary mullite at high temperatures. The mullite phase formed functions to strengthen the bonds between aggregates, resulting in materials with higher cold compressive strength. In addition, the ability of andalusite to form a low-porous protective layer also increases resistance to slag penetration, directly impacting increased castable durability in high-temperature applications. In other words, the presence of andalusite provides structural benefits and protection against chemical attacks.

Another study by Xu et al. (2022) confirms that adding andalusite makes an important contribution to the dimensional stability and high-temperature performance of castable alumina with a low cement content. Although generally low cement content can reduce initial mechanical strength, andalusite overcomes these weaknesses by producing mullite resistant to thermal shock. Mullite functions as a structural reinforcer and a volume stabilizer, thus preventing thermal cracking and deformation during exposure to extreme temperatures. These results show that using andalusite allows for the efficient manufacture of refractory materials, both technically and economically, without relying on high cement content that negatively impacts the environment and processes.

Wu et al. (2022), in their study of Al_2O_3–SiC–C-based castables, indirectly demonstrated the crucial role of andalusite in improving resistance to corrosion by silica and magnesium-based slag. Although the primary focus of the study was on the influence of black carbon, the use of andalusite in the system was shown to form a dense mullite layer, effectively blocking slag penetration and reducing damaging chemical interactions between materials and the environment. The transformed mullite of andalusite increases the chemical resistance and contributes to the dimensional stability and long-term durability of refractory bricks under fluctuating thermal operating conditions.

Zhao et al. (2024) highlight the penetration and corrosion mechanisms of alkali metals in corundum refractory systems and show that the presence of andalusite can inhibit the diffusion rate of alkaline ions. Through microscopic analysis and corrosion tests, it was proven that the mullite formed from andalusite forms a solid barrier that effectively inhibits the permeation of alkaline vapor into the refractory body. These findings are significant in refractory applications used in chemically aggressive environments, such as kilns in the cement industry or non-ferrous metallurgical furnaces. Thus, andalusite not only acts as a structural additive but also as a protective agent against chemical degradation.

Meanwhile, Yuan et al. (2024) reveal the potential of andalusite in a more innovative context, namely as a reactive component in the synthesis of alumina ceramics based on industrial waste. This research involves the formation of SiC nanowhiskers in situ with aluminum support, where andalusite plays a role in supporting the formation of mullite phases and whisker structures that strengthen the material. The synergistic effect between mullite and SiC provides a noticeable improvement in mechanical strength, wear resistance, and high-temperature stability. This shows that andalusite has a dual function: as a structural stabilizing material and an active component in the formation reaction of high-performance ceramic materials, which is relevant in developing sustainable and environmentally friendly refractory technologies.

Weinberg et al. (2021) investigate how this can be achieved through better control of secondary oxides. The high-temperature phase is simulated using thermodynamics software and is associated with microstructure, mineralogy, and composite properties. The results revealed that this system is susceptible to Na_2O, significantly damaging the microstructure. Instead, the addition of TiO_2 and P_2O_5 proved beneficial, allowing for the perfect decomposition of the zircon at 1550 °C while providing the required initial strength. The separation between the matrix and the aggregate due to high matrix shrinkage can be prevented by replacing some of the andalusite with the mineral kyanite, which increases the volume. Based on these findings, new fire-resistant bricks were successfully developed and tested on an industrial scale.

Tang et al. (2021) describe the thermal expansion behavior of andalusite aggregates with different degrees of mulliteization as well as their effect on the properties (resistance to thermal shock and especially volume stability) of the mullite-corundum refractory material, the properties of the mullite-corundum refractory material with uncalcinated andalusite aggregates and which have gone through the precalcination process at different temperatures (1–3 mm) are studied based on permanent line changes, resistance to thermal shock, cold fracture modulus, modulus of elasticity, and apparent porosity. The results of the experiment showed that the stability of the sample volume increased with the increase in the pre-calcite temperature of the andalusite (1300–1500 °C), as the less andalusite residue in the precalculation aggregate would lead to a smaller volume expansion in the refractory sample during the combustion process at high temperatures. Meanwhile, mullite-corundum refractory materials with andalusite aggregates (1–3 mm) calcined at higher temperatures have a better cold fracture modulus value, as increased pre-calcination temperatures can increase the degree of mulliteization, reduce the length of microcracks, and increase the densification of the refractory material. In addition, mullite-corundum flame retardant materials with andalusite aggregates that have not been calcined and have gone through precalcination show good resistance to thermal shock. The residual strength ratio of mullite-corundum refractory materials containing pre-calcinated andalusite aggregates of 1500 °C or 1600 °C is still higher than 90%. Overall, the volume stability and cold fracture modulus of mullite-corundum refractory materials can be significantly improved using pre-calcinated andalusite aggregates of 1500 °C (1–3 mm). All mullite-corundum refractory materials with andalusite aggregates (both those that have not been calcined and those that have been calcined) show good resistance to thermal shock.

Vlček et al. (2023). Analyze the main problem that affects the life of the refractory layer in the furnace is the alkali corrosion that forms during the combustion of biomass, particularly in systems with a SiO_2–Al_2O_3 composition. This corrosion effect is particularly intense compared to conventional technologies designed for traditional fuel combustion. The study focused on developing a new type of andalusite fire-retardant material with higher corrosion resistance to K_2CO_3 and fly ash after biomass combustion. The original andalusite refractory material is A60PT0, with an oxide content of 60 wt.% Al_2O_3 and 37 wt.% SiO_2, a compressive strength of 64 MPa, and an apparent porosity of 15%. In the experiment, four mixtures (labeled A60PT1–A60PT4) were modified primarily using different raw materials and granulometry. Fly ash is characterized through X-ray diffraction analysis (XRD) with the following phases: quartz, calcite, microliny, leusite, portlandite, and hematite. According to X-ray fluorescence (XRF) analysis, the sample contains the following oxides: 47 wt.% CaO, 12 wt.% K_2O, 4.6 wt.% SiO_2, 3.5 wt.% MgO, and some minor oxides such as P_2O_5, MgO, MnO, and Fe_2O_3 in range of 2 to 5 %. The B/A, TA, Kt, and Fu indices determined the tendency of crusting or fouling in the ash. The final material, dense and alusite fireproof, is A60PT4, with a content of 65 wt.% Al_2O_3 and 36 wt.% SiO_2. The properties of this andalusite material include a compressive strength of 106.9 MPa, an apparent porosity of 13%, and a recommended usage temperature of up to 1300 °C. Static tests are carried out using the crucible method for corrosion testing, according to the CSN CEN/TS 15418 standard and the company's internal regulations. The exposure time of the sample was 2 hours and 5 hours at temperatures of 1100 °C and 1400 °C, respectively, for K_2CO_3 and ash. X-ray powder differential analysis, X-ray fluorescence analysis, scanning electron microscopy (SEM), and energy dispersion X-ray spectroscopy (EDS) were used to evaluate the tested samples.

Handoko et al. (2024). His research aims to evaluate the impact of adding asbestos fiber on manufacturing refractory bricks with variations in the base material's composition, including kaolin, fly ash, asbestos, and standard water. Kaolin and fly ash are used in equal proportions, while asbestos content is varied by 0%, 10%, 15%, 20%, and 30% of the total mass. The tests included thermal conductivity and mechanical properties, which were then used as indicators to determine the best formulation. The compressive strength test results showed that the sample without adding quartz sand (0%) had the highest compressive strength value, 14.40 MPa. In impact testing, the composition without asbestos fiber (0%) showed the highest value of 0.084 Joule/mm². Meanwhile, conductivity test results heat show that the composition with 30% quartz sand yields the lowest value, 0.373 K(W/m°C). These findings suggest that adding asbestos fibers can reduce heat conductivity but negatively impacts the mechanical properties of refractory bricks, particularly on compressive strength and impact resistance.

Moehmel et al. (2016). Explain that andalusite is a natural mineral widely used as a raw material for various applications. Due to its distinctive properties, andalusite is also attractive as an aggregate for cast refractory materials and bricks. Andalusite is known to have high volume and thermal stability, high density, and excellent resistance to thermal shock. Nonetheless, the performance of andalusite-based refractory materials – in addition to depending on other factors – is greatly influenced by its chemical composition, which in turn is determined by the amount and type of the following minerals (which vary depending on the location of the mine) as well as the rigor and processing methods (e.g., magnetic separation, heavy media separation, flotation, and electrostatic separation). This study presents the results of a study that compares the performance of various types of raw materials made from andalusite. Different types of andalusite are characterized by chemical and mineralogic composition, as well as by dilatometric testing and heating microscopy. Special attention is paid to the distribution of impurities in different-size fractions. Bricks and cast refractory materials are made from each type of andalusite on a laboratory scale to establish a correlation between the raw material's purity and the refractory material's performance. Thermomechanical properties such as resistance to loads at high temperatures and resistance to slow deformation (creep) are studied, focusing on the influence of impurity levels, their concentration in the matrix, and their effect on microstructures.

Möhmel et al. (2016). His research presented the results of a study that compared the performance of various types of Andalusite raw materials. Various andalusite samples are characterized by their chemical and mineralogy composition. Special attention is also paid to the distribution of impurities across different particle size fractions. Refractory bricks and cast materials are produced from each type of andalusite on a laboratory scale to determine the correlation between the raw material's purity level and the refractory material's performance. Thermomechanical properties such as Refractoriness under Load (RuL) and Creep in Compression (CiC) were also investigated, primarily focusing on the influence of impurity levels, their concentration in the matrix, and their impact on microstructures.

El Haddar et al. (2020). His study explains the efforts to utilize haloysite clay from the Northeast region of the Rif (Nador, Morocco) in silica-alumina refractory materials. To this end, six mixtures (M1–M6) have been tested using aggregates of marl, diatomite, and silica sand to improve the performance of halophytes and develop high-temperature resistant ceramics up to 1300 °C (silicon-alumina refractory "S-Al-R"). Of all the mixtures tested, the M6 mixture showed good technical quality: Porosity (P) = 21.75%; density (d) = 1.94 g/cm³; thermal shrinkage (R) = 2.7%; and flexural strength (Rf) = 29.05 MPa. The addition of 25% recycled alumina "Rec-Al" to the M6 mixture, obtained from silicon-alumina refractory brick waste, significantly improved the mechanical performance of the refractory material (Rf = 45.08 MPa).

Mebrek's (2021) research examines the effect of sintering temperature on microstructural and physical properties for applications such as refractory bricks. A mixture of DD3 Kaolin (from Djebel Debbagh, Guelma-Algeria) and magnesia-carbon refractory brick waste with a relative weight ratio of 95/5 was synthesized via a solid oxide reaction line at sintering temperatures of 1000, 1100, 1200, 1300, and 1400°C. The phases and their transformations during the heating process were analyzed using X-ray diffraction (XRD), scanning electron microscopy (SEM), and helium picometer (AccuPyc II 1340). The XRD results showed changes in the sintered pellets. The phase changes detected were mullite and low α-cristobalite at a sintering temperature of 1000°C. The corderite phase begins to form at 1100°C and increases as the sintering temperature increases, while the mullite and cristrophite phases decrease. At 1400°C, magnesium aluminate spinels are formed in the presence of mullite, low α-cristobalite, and corderite. SEM analysis was performed to observe the morphology of the surface, and it is known that the density decreases as the sintering temperature increases.

Choi et al. (2024). His research aims to provide basic knowledge in the design of refractory materials for furnaces by studying the changes in the properties of refractory materials in the hydrogen atmosphere. Since fire-resistant bricks are thermodynamically stable in a hydrogen atmosphere at 1100 °C, the study sought to detect small changes that might occur. In this experiment, the refractory bricks were made from andalusite raw materials such as chamotte mullite and clay, then heated to 1100 °C in a pure hydrogen atmosphere (100%) for 72 hours. The results showed that the strength of the brick decreased, and the color changed to black due to impurity reduction. In addition, this study also discusses the risk of weathering (slaking) in MgO raw materials because the minimum temperature in fluid reduction furnaces is estimated to reach 400 °C, in contrast to shaft furnaces.

Mou et al. (2025). Analyzing the selection of refractory bricks significantly affects the operational performance of brick structures in high-temperature environments. In this study, a coupled thermal stress model for refractory brick structures was developed and validated through thermal expansion experiments. The study innovatively combined the number of bricks, the thickness of the bricks, and the type of brick material to investigate its effect on the performance of brick structures. The results show that the number of bricks on temperature is not as significant as the influence of brick thickness. However, the number of bricks has a greater impact on the vertical displacement and main compressive stress than the thickness, with a maximum difference of 342.3% and 28.9%, respectively. Compared to the thickness of the brick, the type of brick material has a more significant influence on the vertical displacement and the main compressive stress, with a maximum difference of 77.1% and 67.4%. In addition, the influence of the material properties of the brick on the vertical displacement and the main compressive stress is greater than the number of bricks, with a maximum difference of 77.6% and 65%, respectively. Therefore, in selecting refractory bricks, it is recommended to consider the following order of priority: first, the type of brick material; second, the number of bricks; and finally, the thickness of the brick. This study provides theoretical guidance in the structural design and selection of refractory brick materials for high-temperature applications.

Overall, this study shows that andalusite plays an important role as an aggregate material in improving the physical and mechanical performance of refractory materials, both in brick and castable form. The transformation of the andalusite phase into mullite at high temperatures has been shown to increase the density of the microstructure, resistance to thermal shock, and resistance to slag penetration and alkali corrosion. The addition of andalusite, especially in the form of high-temperature pre-allocation, has a positive effect on the stability of the volume, fracture modulus, and compressive strength of refractory materials. In addition, the chemical composition and purity of andalusite greatly affect the final performance. Impurity levels such as Na_2O can damage microstructures. In contrast, additives such as TiO_2 and P_2O_5 \ cite and partial substitution with minerals such as kyanite have been shown to improve phase stability at extreme temperatures. Some studies have also shown that the rheological and particle distribution characteristics of castable refractory materials containing andalusite can be optimized through mineral processing techniques, such as flotation and magnetic separation. In extreme operating environments, such as hydrogen atmospheres or exposure to corrosive biomass slag, andalusite-based flame retardant materials exhibit superior durability compared to conventional materials. Laboratory and industrial-scale testing (e.g., through the crucible and SEM-EDS tests) have confirmed that parameters such as Wear Ratio, low porosity, and the formation of a protective mullite layer make Andalusit a strategic choice in modern refractory design. Considering all these aspects, using andalusite improves the structural and thermomechanical aspects and provides economic and environmental benefits in the long run through increased service life and reduced maintenance needs. Therefore, andalusite should be a key component in developing high-performance, sustainable flame retardant materials

CONCLUSION

Recent systematic studies (2020–2025) demonstrate that *andalusite* significantly enhances alumina-based refractory bricks by transforming into *mullite* at high temperatures, improving microstructural strength, cold compressive strength, thermal shock resistance, and slag penetration protection while reducing porosity. Bibliometric analysis via VOSviewer reveals dominant research focuses on temperature effects, *mullite* formation, shock resistance, and compressive strength, highlighting the need for multidisciplinary approaches combining materials science, microstructural engineering, and extreme-condition behavior analysis. To advance the field, future research should: (1) optimize *andalusite* particle morphology and size for efficient *mullite* formation; (2) conduct industrial-environment simulations (cement kilns, smelting furnaces) for long-term performance assessment; and (3) develop sustainable methods using local *andalusite* or mineral waste to create eco-friendly, cost-effective refractory materials that maintain high thermomechanical performance while supporting industry sustainability goals.

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