

Thermal Effects on Lead-Free Glazed Ceramics for Home Design

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Abstract

Lead-free glazed ceramics are gaining importance in various aspects of home life design as they offer various benefits such as health and environmental protection. However, the thermal effects of these lead-free glazed ceramics have received limited attention in the design context due to insufficient awareness. This paper aims to present the implications of thermal effects, encompassing both thermal expansion and thermal shock resistance, on lead-free glazed ceramics in the context of home life design. It examines the challenges and opportunities presented by these thermal considerations, highlighting their critical role in ensuring the long-term functionality and safety of ceramics in domestic settings. By addressing these thermal effects, designers and homeowners can make informed choices regarding the selection and use of lead-free glazed ceramics, while minimizing the [risk of lead exposure](#). This aligns with contemporary concerns about health and sustainability and contributes to a safe and environmentally friendly future for ceramic products.

Keywords: *Lead-Free Glazed Ceramics, Thermal Expansion, Thermal Shrinkages, Density, Home Life Design*

Introduction

Modern Interior Design More people are accepting and enjoying ceramic art since it is part of the contemporary, straightforward style that is becoming more prevalent in our culture [1]. The ceramic plates, dinner tables, cups, etc are home life designs that are done by [lead free glazed material](#). Glazed ceramic fabrication is a significant and progressive technique that is clearly traceable due to the production's longevity [2]. Glazing is the process of coating products with glaze to enhance their ornamental and aesthetic features. Glaze is a clear, glass-like inorganic coating. Ceramics receive strength and durability through their glazing. Any glaze's major ingredient is silica, which has as its foundation silicon dioxide, additional ingredients including alumina and borax are also present in glaze [3]. When developing the system, it is vital to find a fusible glaze arrangement that falls within the range of Coefficients of Thermal Expansion (CTE) that the glaze-ceramic body structure can endure. As soon as the arrangement is closed, various CTE values cause tensions to emerge between the pottery form and glaze, which subsequently start to become cold. These tensions rise when the

ceramic material is employed. The amount and kind of stress determine whether or not flaws arise in the glaze layer [4]. Lead has traditionally been used in ceramic glazes and decorations. Lead gives glazes a beautiful, glass-like sheen that reveals vivid colors and artistic designs. It typically suggests dark or vivid colors.

Lead glazing was made from galena (PbS) or litharge (PbO), two fundamental substances. The glazes were put on as a water slurry straight to the ceramic pieces' surfaces [5]. Additionally, PbO can significantly lower the melting point of lead glazes, reducing the sintering temperature and increasing the flow of lead glazes at high temperatures. Lead glazes, on the other hand, are widely recognized to have low durability, leaving them susceptible to extensive wear and even splitting when scratched, preventing their use as radiation-shielding construction materials [6]. Application of lead glaze offers a number of advantages, including a lower melting point, improved transparency, and smoother flow of glaze at elevated temperatures, which results in a glaze with greater gloss and clarity. Low hardness and inadequate chemical stability are drawbacks of low-temperature lead glazes, on the other hand. Excavated lead-glazed ceramic typically underwent varied degrees of deterioration. High-temperature glazes, on the other hand, were frequently well-preserved in the same conditions [7]. Lead-free glazed has been added for the processing of home life-based ceramic designs. One of the dangerous metals that humans are most at risk from is lead. To prevent the risk lead free glazes are used [8]. The various home life designs are developed by using glazed ceramics in the absence of lead. The base glaze and pearlescent glaze were tested to see how they would respond to the sintering conditions and the make-up of the alkali waste [9].

The application of lead-free glazes has mild sticking temperature and consideration for the environment, lead-free minimum-melting temperature glasses are used widely and have a bright upcoming in the electronic industry. However, treating materials at high temperatures while consuming a lot of energy is not environmentally sustainable. Particularly with several options, from the glass to ceramic industry domain, energy conservation is a crucial challenge. The extensive usage of high-temperature furnaces and kilns helps to define entire industries. The amount of energy needed while production makes up a sizable component of the total costs of production. Therefore, the acceptance of power consumption technique was crucial in explaining how the world's energy problem, the state of the environment, and the decline in product costs[10].

The lead-free glazed ceramics are now used for home appliances designed to protect human health from lead material. By using lead-free glazed materials various parameter tests are done. The density test is used to measure how tightly the material is packed together. The next test is porosity and this test is done to find out the characterization of the material's microstructure. Various reviews didn't say about the Thermal test done in lead-free glazed material. The aim of this work is to find Thermal effects in the lead-free glazed ceramics, thermal conductivity is done to measure how well the material conducts or resists the flow of heat and the thermal expansion test is for at which temperature the material changes its shape and melting point are find out.

The major contribution of this research work is:

To find the density of lead free glazed: The density test of lead free glazed ceramic material is to control the quality of ceramic piece with respect to final size.

To know the thermal conductivity: The thermal conductivity of lead free glazed material is used find the ability of the material to conduct heat from its one side to other.

To test the thermal expansion: The thermal expansion of the lead free glazed material is to find that at which temperature the material start change its shape, area and volume

Literature Review

Kolářová, M et al. evaluated glazed ceramic goods' long-term durability and spot fault accumulation or deterioration brought on by the environment's destructive impacts. Thermal analysis strategies revealed that with increasing heating stages, the coefficients of the thermal expansion factor, glass transformation temperature, initial point, and deformed temperature significantly rise. However, the data revealed that stress relationships within glaze-ceramic body systems are unaffected by warming rate [4].

Drawback:

Variations in the readings of the glazing correction point, deformation point, comparative growth, thermal expansion coefficients, and coefficients determined by dilatometry, Thermomechanical analysis, and Differential thermal analysis was found to be barely noticeable to pinpoint the source of flaws. Related to the glaze-chip substance imbalance, analyzed substances had two different types of defects: While the secondary fractures in the relief tile were brought on by the moist environment of the pit, the fundamental cracks in the stove tile were brought on by the improper selection of glaze for the shatter. The glaze flaw in the third floor tile was brought on by the pressure of corrosion products crystallizing.

Klein, S., et al. described the substance, the manufacturing process, and the glaze's composition. The shards' relationship to local industrial activities was also a matter of curiosity. Milled and x-ray microdiffraction were used to evaluate the stage, polarized light microscope and energy-diffusing electron scanning microscopy were used to examine a small portion of the glaze-adhering fragments for elemental information, multi-collector deductively controlled mass spectroscopy was used to analyze the lead isotopes, and milled and x-ray microdiffraction were used to evaluate the stage. Last but not least, the results of the examinations of the glazes' components, stages, and patterns showed that they are closely related to metallurgical processes. [11].

Drawback:

The excavation's findings provide evidence for the consumption of glazed goods in the area, however, it is unclear whether glazing was a part of pottery activity on site due to the lack of nearby evidence

for glaze manufacturing. There is no doubt that the region's pottery and metallurgical industries were intertwined. The availability of the ore directly outside the entrance does not imply that it was used solely, as proven by lead isotope analyses.

Holmqvist, E et al. aimed to identify locally made redware vessels at the locations, chemically describe ceramic and glaze formulas, and investigate glaze use and preparation techniques. iron-rich ceramic bodies, high-lead-content glazes was implemented the lead-oxide alone else the lead-oxide with grit combination. Tin was occasionally used to make the glazes opaque. At comparatively low temperatures and expense, this glazing process produced hermetic pots [12].

Drawback:

On ceramic samples that were manufactured with smooth cross-sections, several analyses were carried out. This method may be inferior to qualitative evaluation using uniformed samples in terms of sample depiction and logical precision, but it was necessary to use it in order to stop elemental emigration from high-lead glazes to [ceramic materials](#), which is what primarily prevents accurate geochemical description in extensive studies. The manufacturing of ceramics with glazes, which are essential components of late medieval redware pottery advances, can now be informed by stage investigations using SEM analysis.

Liu, X et al. explained the strong thermal shudder tolerance and excellent chemical constancy, ceramics mixtures of phase change materials were excellent for storing heat at high temperatures. The rate of energy storage, however, is significantly constrained by composite materials' poor heat conductivity. Due to the continuous heat transfer conduits' densified AlN chain and high heat conduction range, intended composites benefit. This work provides unique approaches to provide storage of thermal energy with excellent thermal conductivity and energy density compatibility using permeable AlN ceramics-built stage variation mixture[13].

Drawback:

Average solar absorption on AlN surfaces has increased significantly from 65% to 91%. As a result, the suggested materials have the capacity to capture thermal and solar energy directly. The observation of extremely rapid thermal energy storing and discharge procedures enables high power density thermal energy stowing. The development of ceramics-based passive thermal energy storage substances is aided by the novel layout of multipurpose phase shift compounds with large stored energy densities, good thermal conductivity, and simultaneous wide solar energy absorption.

Pradell, T et al. detailed that element interdiffusion occurs as a result of the glaze's contact with the ceramic body. An amorphous phase dominates a glaze, but it also contains crystalline phases, bubbles, and fissures. Finally, the glazes are additionally embellished, and a wide range of supplies and techniques were employed. the technical features of glazes, their previous finding and application, and decorative approaches. The information gathering process and analytical methods are also covered [14].

Drawback:

The presence of unresolved elements, newly created immiscible tiny crystallites, bubbles, or nanometric amorphous drops can all contribute to a glaze's transparency. Finally, the use of the glazed object frequently results in the formation of corrosion microstructures. Leaching of glazing parts environmental element assimilation, and formation of new compounds are all aspects of corrosion.

Papulova, G.N et al. explained the goal of the current research was to create colorful lead-free affianced glazes. Lead-free fencing glaze was made with additions of pigments or their combinations in particular amounts with the goal of producing a colorful affianced glaze preparation. Certain organic compounds were used during investigations to examine their effects on the features of the glaze slide and glaze color coating. The impacts of inert extracts-based solid substances on the technological properties of glaze and the quality of glaze coating were explored [3].

Drawback:

According to experimental findings, applying pigments or their combinations to lead-free faience glaze in specific amounts has a positive impact on the technological glaze's quality. The glaze covering's homogeneous, superb gloss, and coverage outperform the decorative quality of colored lead glazes and offer hope for the environment.

Hashimoto, H et al. overviewed that ematite is used in very high temperatures. The procedure used to control the color of red overglaze coatings uses lead-free caustic glasses. The frit alongside the pyrite blend is heated before being viewed through a microscope. Hematite particles slightly enlarged as a result of fusing at low temperatures. The fully developed elements demonstrated scattering analyses and linear plans that mirrored quartz lines, which is a completely different morphology, as compared to particles produced by sintering and before heating. These results suggest that a thorough understanding of frit and heliotrope from the perspective of glass science is needed in order to effectively control the hue of red overglaze enamels. [15].

Drawback:

The crystal development process a high-temperature glass might look like one in a system using frit that contains lead without reliant on the configuration of frit. Though it is generally accepted that red akae turns out better when lead-containing frit is used than when lead-free frit, exact cause not remained identified. Unable to be explained, such empirical common knowledge

Vajdi, M et al. described the TiB₂-SiC composite's structure and heat conductivity investigated. The disk-shaped pellets were made using spark plasma sintering at 1800 °C and 40 MPa of pressure. After the addition of graphene nano-platelets, the microstructure of the TiB₂-SiC was better, more solid, and even, according to descriptions of polished regions and cracked shells from [scanning electron microscopy](#). Utilizing the laser flash method, the thermal expansion of the test material was taken

into account, and the thermal conductivity of the sintered specimens was then evaluated [16].

Drawback:

To determine the thermal conductivity of samples and evaluate their thermal diffusivity, the laser flash method was used. Both samples exhibited a gradual reduction in thermal conductivity as temperature rose. Though graphene is advanced thermal conductivity, a minor addition of graphene nanoplatelets led to a 7% reduction in thermal conductivity values.

Kuzmanovic, M et al. specify that it was intended to demonstrate the potential of Laser-Induced Breakdown Spectroscopy (LIBS) by analyzing pottery ruins, that are frequently one of the abundant items discovered in ancient ruins. The documentation of components unique to inanimate stains used in decorating was reviewed to determine the logical strength of this spectroscopy. Based on particular components detected on glazes' LIBS spectra, relationships between the basic components of glaze and the colors of the glazed exterior were discovered. Temperature and electron number density, two crucial variables for plasma characterization, were calculated from the spectral data [17].

Drawback:

In order to guarantee that the glaze spectra only represented the glaze composition. Excitation temperatures ranged from 9227 °C to 10727 °C, and density ranged from $2.0 \cdot 10^{23}$ to $3.2 \cdot 10^{23} \text{ m}^{-3}$, according to estimates based on spectral data. The current study's experimental findings show that LIBS is a reliable method for detecting the elements present in ceramic glazes, with the added potential of outward and penetration outlining of the glaze configuration.

Yin, X et al. explained in this study, the degraded glazing contained a layer of dendritic PbCO_3 crystalline and an amorphous Si-rich structure. These incrustational characteristics shed light on the interactions governing the deterioration of glazing, the fractional crystallization of lead compounds, and the growth of multi-layered structures. Furthermore, research comparing recently developed lead-based glazes provides compelling evidence for lead alteration and stresses the crucial role stains play in glaze deterioration. The most recent findings contribute to a better understanding of lead-silicate glass solids and the long-lasting effects of lead on funeral situations [18].

Drawback:

The colorants in glazes were discovered to have a substantial impact on how they degraded. Innovative research on the impacts of material swaps on newly created lead-silicate glazes provides a clear explanation for lead separation, phase development, and the effects of pigments on glaze erosion phase. The findings and analyses provide a clear picture of how the interactions between the lead-silicate glazes and the flowing environment resulted in material modification.

Problem Statement and Study Objective

A lack of comprehensive understanding of the thermal effects of lead-free glazed ceramics in the context of home life design results in a significant knowledge gap that prevents designers and homeowners from making informed decisions. Furthermore, limited research on the thermal expansion behaviour of lead-free glazed ceramics makes it challenging to predict and prevent potential structural failures or damage in residential applications, raising concerns about the long-term performance and safety of these materials. Inadequate consideration of thermal effects can lead to unexpected and costly failures [11-15]. An important aspect needs to be explored more thoroughly. This study aims to comprehensively investigate and analyze the effects of thermal effects on lead-free glazed ceramics in the context of domestic living design. It evaluates the thermal expansion behaviour of lead-free glazed ceramics and examines how variations in the mixing and firing processes affect their response to temperature fluctuations. This study will help make informed decisions about the selection, placement, and maintenance of lead-free glazed ceramics, ensuring their long-term performance and safety in domestic environments.

Experimental Procedures

Materials

Clay, Soda feldspar, hydrous kaolin, soapstone talc, Frits, borax, sodium bicarbonate, zirconium, cobalt oxide, binders, and plasticizers.

Sample Preparation

The study follows ASTM C326 and ISO 10545 standards for ceramics. A lead-free pottery mixture is prepared by mixing 100 g of clay with 20% soda feldspar, 20% hydrous kaolin, 5% soapstone talc, 20% frits, 5% borax, 10% sodium bicarbonate, and 5% zirconium. Water was added and mixed well until the required viscosity was reached. This mixture is then moistened and this pliable clay is molded into the desired shapes in hand modeling and mold casting techniques. Materials such as frits, boron, and flux are mixed with water to form a glaze. Glaze and composite soak for 2 minutes to meet aesthetic and functional requirements. This glaze gives a stunning look and provides a protective layer to the ceramics. It is then allowed to dry thoroughly before firing. Fired in a furnace at a temperature of 1000 to 1200 degrees Celsius in an oxidizing environment. Materials such as frits, boron, and fluxes are mixed with water to form a glaze slurry. Glaze consistency and composition are used to meet aesthetic and functional needs. Lead-free glazes are applied to pottery, then dipped and poured, ensuring smooth and even application. This glaze gives a stunning look and provides a protective layer to the ceramics.

Density Measurements

In distilled water and a vacuum, the prepared sample's density weight was measured. An Accu Pyc 1330 gas displacement pycnometer is used to determine the density of lead-free glazed ceramics. By calculating the change in helium pressure within a specified volume, density is determined. It was accurate to within 0.001g/cm³. Thus, the [nanocomposite sample](#) was weighed in air to determine its mass under typical circumstances. On the basis of Archimedes' principle, the lead-free glazed ceramics are then submerged in distilled water in a container. The sample moves an equivalent volume of liquid when submerged in water. This weight change was measured to determine density. The following Eq (1) is used to determine the density (ρ) of lead-free glazed ceramics.

$$\rho = m / V \quad (1)$$

Here, ρ is density, m is mass, and V is volume.

Thermal Conductivity Measurements

The thermal conductivity test procedure for lead-free glazed ceramics is a critical examination aimed at determining the material's ability to conduct heat, a fundamental property that influences its performance in various applications. Temperature sensors are affixed to the ceramic surface to record temperature changes during the test. Heat is then applied to one side of the ceramic, generating a controlled heat flux that flows through the material. As the system reaches a steady state, temperature variations are continuously monitored. Using recorded temperature data, sample dimensions, and the principles of heat conduction, the thermal conductivity of the lead-free glazed ceramic is calculated. The resulting value is expressed in watts per meter-kelvin (W/m·K) and serves as a crucial metric for understanding how effectively the material conducts heat. The thermal conductivity of lead-free glazed ceramics was calculated according to Equation (2) using the recorded temperature data, the dimensions of the specimen, and the principles of thermal conductivity.

$$k = QL / (A\Delta T) \quad (2)$$

Here, k is thermal conductivity (W/m·K), Q is the heat-transfer rate (W), L is the specimen thickness (m), A is the cross-sectional area (m²), and ΔT is the temperature difference across the specimen (K).

Thermal Expansion Measurements

This test is crucial in determining the ceramics' dimensional stability and their suitability for various applications. The lead-free glazed ceramic ensures that the samples are first free of defects or impurities that could affect the results. These samples are then subjected to a controlled thermal expansion test apparatus, which typically consists of a specialized instrument that can precisely measure dimensional changes over a range of temperatures [19]. The ceramic samples are heated

gradually while being monitored for any variations in size. By measuring the changes in length, width, or other relevant dimensions, the coefficient of thermal expansion (CTE) is determined. The CTE value measures how much the ceramics expand or contract as a function of temperature and is represented in ppm/°C. The thermal expansion test for lead-free glazed ceramics involves measuring the change in dimensions of a ceramic sample as it is subjected to temperature variations. The coefficient of thermal expansion (CTE) is calculated using the Equation (3).

$$CTE = \Delta L / (L_0 \Delta T) \quad (3)$$

This ratio is expressed in °C⁻¹; multiply by 10⁶ to express it in ppm/°C.

Here, CTE is the coefficient of thermal expansion, ΔL is the change in specimen length, L_0 is the initial specimen length, and ΔT is the temperature change in °C.

Results and Discussion

Density Analysis

Density test results in lead-free ceramics composites provide essential information about the mass and volume of the material, helping to characterize its physical properties and assess its suitability for various applications. Sintering temperature-dependent density values of the lead-free glazed ceramic materials are presented in Table 1.

Table 1. Density data from the original chart

Sintering temperature (°C)	Density (g/cm ³)	Original error-bar magnitude
1000	2.203	±0.015
1050	2.2566	±0.03
1100	2.29	±0.02
1150	2.323	±0.015
1200	2.4	±0.01

The density of lead-free glazed ceramics prepared at sintering temperatures of 1000 to 1200 °C was studied, ranging from 2.1 to 2.4 g/cm³, which shows that it plays an important role in thermal

behaviour. This affects heat retention and distribution. As the sintering temperature of lead-free glazed ceramics increased, their density also increased because the higher temperature allowed the ceramic particles to spread and bond more effectively. This leads to a denser and more compact microstructure. This increased density may result in less porosity. Lowering the sintering temperature reduces the density of lead-free glazed ceramics. This may be due to incomplete sintering, insufficient particle bonding, or retention of some porosity within the material. Ceramics sintered at low temperatures have a more open structure and lower density.

Thermal Shrinkage Analysis

Thermal shrinkage analysis results of lead-free glazed ceramics were investigated to determine how these materials respond to temperature variations. The percentage shrinkage was investigated in the temperature range of 900 to 1200 °C. Temperature-dependent shrinkage percentage of the lead-free glazed ceramic materials are presented in Table 2.

Table 2. Thermal shrinkage data from the original chart

Temperature (°C)	Thermal shrinkage (%)
900	95
905	94.54
910	93.68
915	93.32
920	92.76
925	92
930	91.46
935	90.58
940	90.62

Temperature (°C)	Thermal shrinkage (%)
945	89.6
950	89
955	88.403
960	87.83
965	87.25
970	86.63
975	86.1
980	85.43
985	84.87
990	84.25
995	83.63
1000	83.2
1005	82.42
1010	81.82
1015	81.22
1020	80.62

Temperature (°C)	Thermal shrinkage (%)
1025	80.2
1030	79.45
1035	78.82
1040	78.24
1045	77.62
1050	76.2
1055	75.124
1060	73.84
1065	72.25
1070	70.62
1075	69.12
1080	67.41
1085	65.83
1090	64.23
1095	62.64
1100	61.2

Temperature (°C)	Thermal shrinkage (%)
1105	59.43
1110	57.23
1115	54.93
1120	52.72
1125	50.52
1130	48.33
1135	47.2
1140	45.63
1145	44.25
1150	42.86
1155	41.49
1160	41.407
1165	41.4
1170	41.4
1175	41.3
1180	41.2999999999

Temperature (°C)	Thermal shrinkage (%)
1185	41.2999999999
1190	41.1999999999
1195	41.16
1200	41.13

Thermal shrinkage analysis of lead-free glazed ceramics revealed non-linear or anomalous behaviour. The amount of shrinkage varied in different temperature ranges. This behaviour suggests challenges in design and manufacturing. It is reported to be particularly suitable for applications requiring a tight fit and secure bond at elevated temperatures. This property is beneficial in areas such as thermal insulation or refractory linings.

Thermal Conductivity Analysis

Understanding thermal conductivity is very important for selecting, designing and using lead-free ceramic composites in a wide range of applications. Thermal conductivity test results on lead-free ceramic composites are presented in Table 3.

Table 3. Thermal conductivity data from the original chart

Temperature (°C)	Thermal conductivity (W/m·K)	Original error-bar magnitude
100	1.23	±0.067
200	1.45	±0.071
300	1.56	±0.065
400	1.68	±0.05
500	1.9	±0.09

Thermal conductivity analysis of lead-free glazed ceramics revealed low thermal conductivity. This refers to their effectiveness as thermal insulating materials. The test results showed a low thermal conductivity of 1.23 to 1.9 W/m K, suitable for applications requiring thermal insulation, which results support previous studies [20]. Thermal conductivity varies with temperature but does not change greatly. The thermal conductivity of lead-free glazed ceramics revealed an increase with increasing temperature.

Thermal Expansion Analysis

Thermal expansion in lead-free ceramics composites reveals the material's tendency to change in dimension when subjected to temperature variations. Temperature-dependent thermal expansion of the lead-free glazed ceramic materials are presented in Table 4.

Table 4. Thermal expansion data from the original chart

Temperature (°C)	Thermal expansion (ppm/°C)	Original error-bar magnitude
100	5.18	± 0.57735026919
200	5.45	± 0.75
300	6.35	± 0.51
400	7.1	± 0.308290376865
500	7.83	± 0.31

The CTE of lead-free glazed ceramics was found to be approximately 5.18×10^{-6} to 7.83×10^{-6} /°C temperature range of 100 to 500 °C. These results indicate that lead-free glazed ceramics have moderate CTE, making them suitable for applications where dimensional stability is important but not highly constrained, which results support previous studies [21].

Conclusion

The study results on the implications of thermal effects on lead-free glazed ceramics for home life design provided valuable insights into the behaviour of these materials in domestic environments. The investigation into various thermal properties, including density, thermal conductivity, thermal expansion, and thermal shrinkage with sintering, has shed light on the complex nature of lead-free

glazed ceramics when subjected to temperature fluctuations. These findings underscore the importance of considering thermal effects in the selection, placement, and maintenance of these ceramics within homes. First, the density of lead-free glazed ceramics ranged from 2.1 to 2.4 g/cm³, showing that it plays an important role in thermal behaviour. This affects heat retention and distribution. This insight informs the optimal use of ceramics in applications such as cookware and architectural elements, where thermal stability is essential. Second, the thermal conductivity of these materials ranged from 1.23 to 1.9 W/m K at temperatures ranging from 100 to 500 °C. Help design efficient heating and cooling systems inside homes. The study highlights the need to balance thermal insulation and conductivity when incorporating lead-free glazed ceramics into architectural design. Investigation of thermal expansion and contraction has revealed challenges associated with rapid temperature changes. the thermal expansion of these materials ranged from 5.1 x10⁻⁶ to 7.83 x10⁻⁶/°C at temperatures ranging from 100 to 500 °C.

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