

EVALUATION OF THERMAL CONDUCTIVITY AND SPREADING BEHAVIOR OF MAGNESITE REFRACTORY BRICKS DEPENDING ON PRODUCTION PARAMETERS

Onur Töre^{1*}, Usame Demir²

^{1*} Bilecik Şeyh Edebali University, Graduate education institute, Department of Mechanical Engineering, 11100, Bilecik, Türkiye

² Bilecik Şeyh Edebali University, Engineering Faculty, Department of Mechanical Engineering, 11100, Bilecik, Türkiye
ORCID Code: ¹0009-0003-0991-7974, ²0000-0001-7383-1428

ABSTRACT

This study investigated the thermal conductivity and thermal diffusivity properties of magnesite bricks produced at different pressures (1400, 1500 and 1600 kg/cm²) and different thicknesses (20 mm, 30 mm and 40 mm). The measurements were carried out in the temperature range of approximately 24-25.6 °C and the temperature coefficient of resistance (TCR) remained approximately constant (around 0.00466 K⁻¹) for all samples. According to the data obtained, as the pressure increases, the density of the bricks increases and the porosity decreases. This leads to an increase in thermal conductivity. Especially the highest thermal conductivity (20.25 W/m-K) and thermal diffusivity (0.57 m²/s) values were obtained for the bricks produced at 1600 kg/cm² pressure and 20 mm thickness. In terms of thickness, a general decrease in the coefficient of thermal diffusivity was observed with increasing thickness. This indicates that thicker structures show more resistance to thermal energy transfer. For example, the lowest thermal diffusivity value (0.19 m²/s) was recorded for the 30 mm thick specimen under 1400 kg/cm² pressure. In conclusion, magnesite bricks' thermal performance varies depending on the applied pressure and the geometric thickness. Denser and more conductive bricks are obtained under high pressure, while heat dissipation is limited as the thickness increases. Therefore, the selection of refractory material should be optimized by considering these two parameters.

Keywords: Magnesite brick, refractory material, thermal conductivity, thermal diffusivity, Hot Disk TPS 2500 S

INTRODUCTION

Refractory materials play a critical role in maintaining structural integrity and thermal performance in high-temperature applications (Feng et al., 2021). The efficient operation of kiln and clay systems used in power generation, cement, glass, iron, and steel industries depends on high-performance refractory stability (Vasić et al., 2023). Magnesite (MgO) based refractories are the indispensable building blocks of these systems thanks to their superior properties such as high melting temperature, chemical

resistance, and thermal stability(Q. Chen et al., 2023). Refractory performance is not limited to mechanical strength; thermophysical parameters such as thermal conductivity (k) and thermal diffusivity (α) are of great importance, especially in terms of energy conservation and heat management(Borges et al., 2025). In the literature, many studies have reported that these parameters vary depending on material microstructure, porosity, and particle size(Usseglio-Viretta et al., 2020). For example, in polycrystalline refractory materials, grain boundaries are known to have significant effects on thermal resistance, while in porous materials heat transfer is limited at the gas-solid interface(Smith et al., 2003). In recent years, environmental sustainability has also become prominent in refractory research(Y. Chen et al., 2023). In particular, the recovery of waste magnesite refractories is evaluated using criteria to reduce the carbon load (Muñoz et al., 2020). Furthermore, magnesite configurations modified with biological additives such as lignin stabilizers have been shown to improve thermal and mechanical durability(Manni et al., 2022; Sarkar, 2023). In terms of thermal measurements, TPS (Transient Plane Source) based instruments such as the Hot Disk TPS 2500 S are capable of simultaneously determining both thermal conductivity and diffusivity with high precision and accuracy(Hot Disk Instruments, n.d.). This technology is particularly preferred for heterogeneous materials (e.g. magnesite bricks); the compliance of this zeroing technique with the ISO 22007-2 standard is widely accepted in the industry(Yina & Talapin, 2013). This study aims to experimentally evaluate the thermal performance of magnesite bricks produced at different pressures (1400-1600 kg/cm²) and thickness (20-40 mm) variations. The production process was based on realistic protocols realized in an industrial-scale company (SÖRMAŞ A.Ş.). The measurements performed using a Hot Disk TPS 2500 S device aim to reveal the effects of material microstructure optimization on thermal conduction. In summary, while it is known in the literature that factors such as particle boundaries, porosity, microstructure and additives have significant thermal effects, in this study, the experimental approach based on the optimization of many parameters is supported by clear results and original data that can guide industrial applications are presented.

MATERIALS AND METHODS

The refractory samples examined in this study were obtained from the industrial production processes of SÖRMAŞ A.Ş. operating in Turkey. The raw materials used in producing the samples, the shaping and firing conditions applied, experimental measurement procedures, and analysis methods are presented in detail below.

Sample Production and Preparation Process

The main raw materials used in the production of refractory bricks are sintered spinel, seawater-sintered magnesite, totanine, and water. These raw materials are pre-treated and reduced to specific grain sizes. Sintered spinel was separated into 0-1 mm and 1-3 mm fractions, while seawater sintered magnesite was prepared in 63 μ m powder, 0-1 mm, 1-3 mm and 3-5 mm fractions. Totanine and water

were added to the mixture as a binder, and the additives were workability-enhancing. These components prepared according to the determined ratios were weighed to form a 1250 kg blend. In order to obtain a homogenous mixture, the raw materials were mixed in a Gustav Eirich brand mixer for 10 minutes and then transferred to the press bunker with a transfer trolley. The forming process was carried out using LAIES HPF III model hydraulic press with a capacity of 1600 tonnes. Three different pressure levels were applied within the scope of production parameters: 1400, 1500 and 1600 kg/cm² (approximately 137, 147 and 157 MPa). In the same way, bricks of three different thicknesses were produced: 20 mm, 30 mm and 40 mm. The base dimensions of the bricks were kept constant at 198 × 220 mm for all specimens. After pressing, the dimensions and raw densities of the specimens were checked, followed by drying to remove moisture. The dried bricks were fired in a 115 m long tunnel kiln at a temperature of 1540 °C, which is considered suitable for magnesite-based refractories. This temperature was reached in the kiln section, which is defined as the "fire zone," and the bricks were kept here for about 2 hours. The total firing time in the kiln was 72 hours (3 days).

The bricks produced after firing were made ready for analyses to be tested in SÖRMAŞ A.Ş. R&D laboratory. Sample views before and after production are shown in Figure 1 and the flow chart of the production process is shown in Figure 2.



Figure 1 Pre and Post Production Views of the Samples

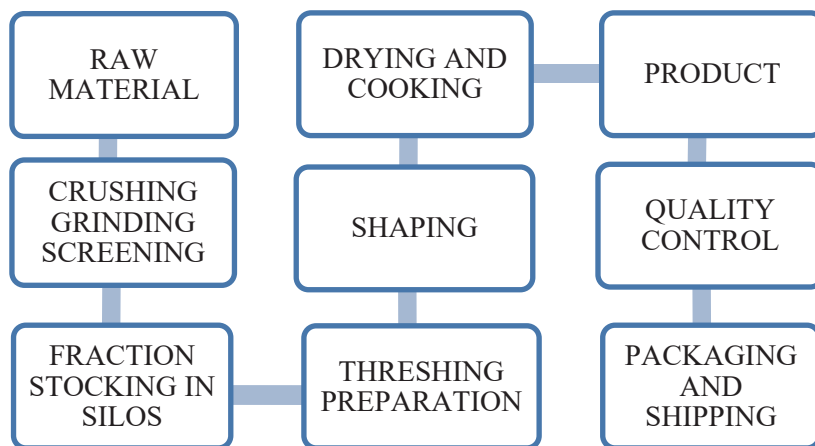


Figure 2 Production Process Flow Chart

Measurement of Thermal Properties

A total of nine different samples were selected from the fired refractory bricks. Each sample represents different combinations of pressure and thickness. Thermal conductivity, thermal diffusivity and temperature coefficient of resistance (TCR) values were determined on these samples. The measurements were performed using a Hot Disk TPS 2500 S Thermal Constants Analyzer. This device works with the Transient Plane Source (TPS) method and can simultaneously measure thermal conductivity and diffusivity coefficients with high precision. Due to its high accuracy, the TPS method is especially preferred for refractory materials with heterogeneous structures.



Figure 3 HotDisk TPS2500S Thermal Conductivity Measurement Device(*Hot Disk Instruments, n.d.*)

During the measurement process, the special nickel sensor of the device was positioned between the two samples; the sensor functioned simultaneously as a heat source and a temperature measurement tool. The samples were tested at room temperature (approximately 24-26 °C), and the power and time settings determined automatically by the device were applied to each measurement. The data obtained were analysed through the instrument software and thermal conductivity (W/m-K), thermal diffusivity (m²/s) and TCR (K⁻¹) values were calculated. The measurement results were classified and evaluated according to the production parameters of the samples and the effects of these parameters on thermal performance were examined.

EXPERIMENTAL RESULTS

In this section, thermal conductivity and thermal diffusivity values of magnesite based refractory bricks produced at different pressures and thicknesses were analysed. The measurements were carried out using a Hot Disk TPS 2500 S device at conditions close to room temperature. The measurement results were correlated with the production parameters (pressure and thickness) and presented graphically.

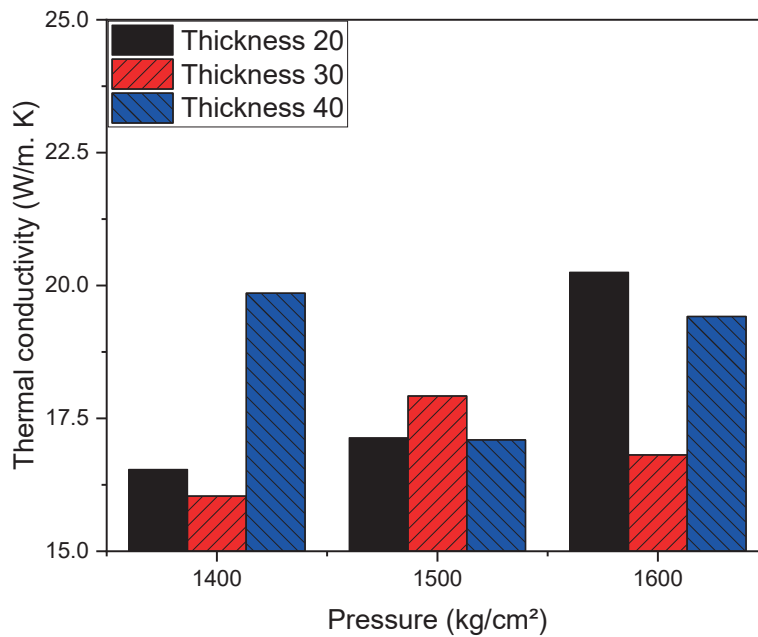


Figure 4. Thermal conductivity values of magnesite bricks with different thicknesses under varying compaction pressures

As seen in Figure 4, thermal conductivity values generally tend to increase with increasing pressure. Thermal conductivity is a critical thermophysical parameter that indicates how much heat a material transfers per unit area per unit time. According to the experimental results, it was observed that the thermal conductivity values generally increased as the pressure increased. This can be explained by increased intergranular contact areas and decreased porosity in the specimens formed under high pressure. The thermal conductivity is quite low since the pores are generally filled with air. Therefore, the decrease in the pore ratio increases the efficiency of the total heat transfer paths in the material and facilitates heat conduction. For example, the sample with a pressure of 1600 kg/cm² and a thickness of 20 mm reached the highest conductivity value (20.25 W/m-K). This value is a result of the effect of high density combined with low thickness. In contrast, the specimen with 1400 kg/cm² and 30 mm thickness measured the lowest conductivity value (16.037 W/m-K). This indicates that the combination of low pressing pressure and medium thickness creates more micropores and a lack of

contact within the material. The thickness parameter has a more limited effect on the thermal conductivity compared to the pressure. This indicates that the thermal conductivity is more sensitive to the chemical and physical properties of the material (porosity, grain density, binder phases)(Brosa Planella et al., 2021; Hung Anh & Pásztor, 2021a). Similar results have been frequently emphasized in the literature. Reducing micropores and binder phases in dense and compact refractories directly increases conductivity by increasing the continuity of heat carrier pathways.

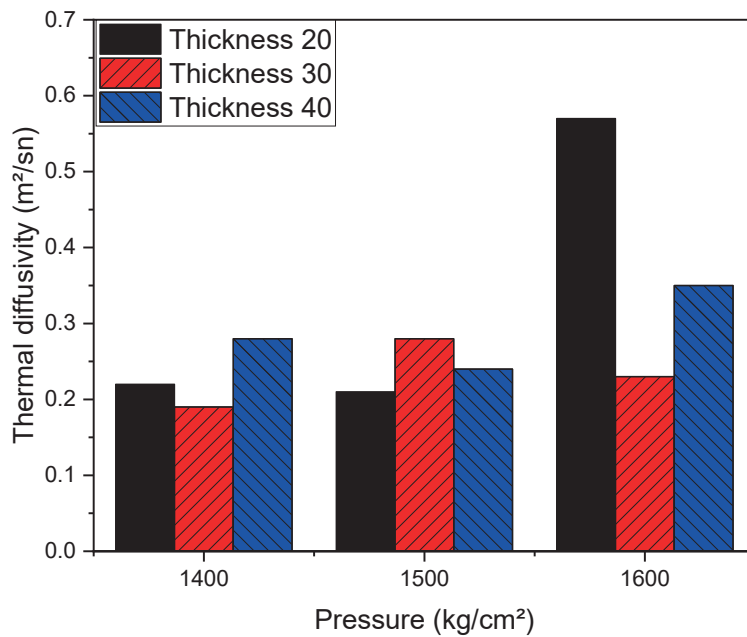


Figure 5. Thermal diffusivity values of magnesite bricks with different thicknesses under varying compaction pressures

Figure 5 shows the effect of thickness change on the thermal diffusion coefficient. The thermal diffusivity coefficient indicates how quickly the material reacts to a temperature change and how quickly it conducts heat. This parameter is important for understanding the thermal behaviour of the material, especially during transient (time-dependent) temperature changes. According to the experimental findings, pressure and thickness combinations significantly affect thermal diffusivity. A remarkable result is the highest diffusivity value of 0.57 m²/s measured at 1600 kg/cm² pressure and 20 mm thickness. This is the result of the combination of both the dense structure obtained by high pressing and the low thermal resistance provided by the low thickness. Such a structure offers a refractory material structure that can react quickly to temperature change, effectively conducting heat. On the other hand, the lowest thermal diffusivity value of 0.19 m²/s was measured at a pressure of 1400 kg/cm² and a thickness of 30 mm. This shows that the thicker structure creates greater resistance to heat flow, and the porous microstructure slows down heat dissipation. While heat travels a longer

path through the thick material, it is also trapped in the micropores and the conduction velocity decreases. These findings are in line with the effects of porosity on propagation reported by (Sharma & Dubey, 2023). Furthermore, the coefficient of expansion is directly related to the heat capacity and density of the material. Increased porosity reduces the heat capacity, while low density severely limits the heat-carrying capacity. This results in low diffusivity values.

DISCUSSION

In this study, the thermal properties of magnesite-based refractory bricks produced at different pressing pressures and thicknesses were investigated, and the data obtained were evaluated in terms of the effects of production parameters on thermal conductivity and thermal diffusivity. The findings reveal that the physical and chemical properties of the material play a decisive role on the heat transfer behavior.

It was observed that an increase in pressing pressure increases the physical density of the refractory bricks and decreases the porosity, resulting in a significant increase in thermal conductivity. Dense structures are known to facilitate heat transfer by minimizing thermal resistances caused by air gaps. The results confirmed this with high thermal conductivity (20.25 W/m-K) and diffusivity (0.57 m²/s) values, especially in 1600 kg/cm² pressure-formed specimens. These results align with the density-conductivity relationship in the literature (Yu et al., 2023). Pressing also strengthens the intergranular bond structure, increases the physical integrity of the material and provides continuity in heat transport pathways. This has a positive effect on thermal conductivity. The pressure-sensitive thermal behavior of refractory materials is an important production parameter that must be taken into account, especially in high-temperature furnace designs. Thickness variation has shown a significant effect, especially on the thermal diffusivity coefficient. Increasing thickness limits the propagation rate, requiring heat to travel a longer path through the material. This can be explained by the fact that the thicker structure acts as a thermal resistance, reducing the rate of energy transfer. The low diffusivity value (0.19 m²/s) measured in the 30 mm thick specimen under 1400 kg/cm² pressure is a clear example of this effect. On the other hand, the effect of thickness on thermal conductivity was more limited and showed a weaker trend compared to the pressure factor. This suggests that conductivity is more related to the material's physical density and chemical composition. Parameters such as chemical bond structures, doping phases and grain size distribution within the material are decisive at this point (Hung Anh & Pásztor, 2021b; Zhou et al., 2022).

The results obtained support the relationships between physical density, porosity and thermal properties of refractory materials in the existing literature. However, this study makes a unique contribution in that it is based on samples obtained from industrial-scale production processes. In particular, the measurements made with the Hot Disk TPS 2500 S instrument directly and reliably reflect the effect of changes in physical properties on thermal performance, which increases the

scientific power of the study. Furthermore, this study has shown that optimizing production parameters can improve thermal conductivity and thermal diffusivity. Such optimizations are critical to reducing thermal losses and increasing refractory life in energy-efficient industrial systems.

CONCLUSION

In this study, the thermal conductivity and thermal diffusivity properties of magnesite-based refractory bricks produced at different pressing pressures (1400, 1500 and 1600 kg/cm²) and thicknesses (20 mm, 30 mm, 40 mm) were experimentally evaluated. The production was carried out under industrial-scale conditions, and the measurements were taken with a high-accuracy Hot Disk TPS 2500 S device.

The findings can be summarized as follows:

Increasing the pressing pressure increases the physical density of the material and reduces porosity, resulting in a significant increase in both thermal conductivity and thermal diffusivity. The highest conductivity and diffusivity values were obtained under 1600 kg/cm² pressure.

An increase in thickness shows a limiting effect, especially on thermal diffusivity. Thicker specimens exhibit a greater resistance to heat flow, slowing down the response of the material to temperature changes. Thermal conductivity, conversely, was less affected by thickness variation and more related to density.

The temperature coefficient of resistance (TCR) remained approximately constant in all samples, reflecting the thermal stability of magnesite-based refractory materials.

These results clearly demonstrate the need for careful control of manufacturing parameters in refractory material design. Determining the optimum pressure and thickness combination is critical, especially if energy efficiency is targeted in high-temperature applications.

In future studies, using different additives, comparison of binder types, phase analysis, detailed microstructural characterization (e.g. by SEM and XRD analysis), and chemical composition will provide a more holistic view of material performance. Furthermore, the effects of prolonged use under high temperatures on the material's thermal properties are also available for investigation. This study provides a holistic approach covering the whole process from production to measurement, which will shed light on both academic and industrial applications and provide important technical data to decision-makers in refractory engineering.

ACKNOWLEDGEMENTS

We would like to thank Sörmaş A.Ş. for providing all the opportunities during the conduct of this study.

REFERENCES

- Borges, O. H., Wulf, R., Aneziris, C. G., & Pandolfelli, V. C. (2025). Impact of atmospheric conditions on the high-temperature thermal conductivity of novel Cr-free refractory materials. *Journal of the American Ceramic Society*, *108*(8), e20548. <https://doi.org/10.1111/JACE.20548;WGROU:STRING:PUBLICATION>
- Brosa Planella, F., Ai, W., Boyce, A. M., Wang, A. A., Zheng, Q., Hao, M., Miao, R., Schaadt, J., & Dames, C. (2021). Advances in thermal conductivity for energy applications: a review. *Progress in Energy*, *3*(1), 012002. <https://doi.org/10.1088/2516-1083/ABD082>
- Chen, Q., Yan, W., Schafföner, S., Wu, H., Han, B., Zhang, J., & Li, Y. (2023). Microstructures and strength of microporous MgO-Mg(Al, Fe)₂O₄ refractory aggregates. *Journal of the European Ceramic Society*, *43*(6), 2654–2662. <https://doi.org/10.1016/J.JEURCERAMSOC.2023.01.023>
- Chen, Y., Song, B., & Fang, C. (2023). Refractories analysis, teaching train and entrepreneurial guidance for college students. *International Journal of Educational Science and Theory*, *2*(1), 18–21. <https://doi.org/10.26789/IJEST.V2I1.1749>
- Feng, R., Feng, B., Gao, M. C., Zhang, C., Neufeind, J. C., Poplawsky, J. D., Ren, Y., An, K., Widom, M., & Liaw, P. K. (2021). Superior High-Temperature Strength in a Supersaturated Refractory High-Entropy Alloy. *Advanced Materials*, *33*(48), 2102401. <https://doi.org/10.1002/ADMA.202102401;REQUESTEDJOURNAL:JOURNAL:15214095;WGROU:STRING:PUBLICATION>
- Hot Disk Instruments*. (n.d.). Retrieved June 23, 2025, from <https://www.hotdiskinstruments.com/>
- Hung Anh, L. D., & Pásztor, Z. (2021a). An overview of factors influencing thermal conductivity of building insulation materials. *Journal of Building Engineering*, *44*, 102604. <https://doi.org/10.1016/J.JOBE.2021.102604>
- Hung Anh, L. D., & Pásztor, Z. (2021b). An overview of factors influencing thermal conductivity of building insulation materials. *Journal of Building Engineering*, *44*, 102604. <https://doi.org/10.1016/J.JOBE.2021.102604>
- Manni, A., Matadi Boumbimba, R., Mikdam, A., El Bouari, A., Addiego, F., Meziani, J., & Wary, M. (2022). Magnesite and dolomite micro-particles: preparation, physical properties and application in bio-based polymer composite. *Polymer Bulletin*, *79*(4), 2149–2171. <https://doi.org/10.1007/S00289-021-03609-W/FIGURES/16>
- Muñoz, I., Soto, A., Maza, D., & Bayón, F. (2020). Life cycle assessment of refractory waste management in a Spanish steel works. *Waste Management*, *111*, 1–9. <https://doi.org/10.1016/J.WASMAN.2020.05.023>
- Sarkar, R. (2023). *Refractory technology: fundamentals and applications*. CRC Press.
- Sharma, A., & Dubey, D. K. (2023). Effect of porosity on shock propagation behaviour of single crystal aluminium: A molecular dynamics investigation. *Mechanics of Materials*, *177*, 104535. <https://doi.org/10.1016/J.MECHMAT.2022.104535>
- Smith, D. S., Fayette, S., Grandjean, S., Martin, C., Telle, R., & Tonnessen, T. (2003). Thermal resistance of grain boundaries in alumina ceramics and refractories. *Journal of the American Ceramic Society*, *86*(1), 105–111. <https://doi.org/10.1111/J.1151-2916.2003.TB03285.X;CTYPE:STRING:JOURNAL>
- Usseglio-Viretta, F. L. E., Finegan, D. P., Colclasure, A., Heenan, T. M. M., Abraham, D., Shearing, P., & Smith, K. (2020). Quantitative Relationships Between Pore Tortuosity, Pore Topology, and Solid Particle Morphology Using a Novel Discrete Particle Size Algorithm. *Journal of The Electrochemical Society*, *167*(10), 100513. <https://doi.org/10.1149/1945-7111/AB913B>
- Vasić, M. V., Radovanović, L., Pezo, L., & Radojević, Z. (2023). Raw kaolinitic–illitic clays as high-mechanical-performance hydraulically pressed refractories. *Journal of Thermal Analysis and Calorimetry*, *148*(5), 1783–1803. <https://doi.org/10.1007/S10973-022-11848-W/TABLES/10>
- Yina, Y., & Talapin, D. (2013). The chemistry of functional nanomaterials. *Chemical Society Reviews*, *42*(7), 2484–2487. <https://doi.org/10.1039/C3CS90011H>

- Yu, H., Ng, K., & Lau, C. (2023). New coal char-based bricks: Effects of curing temperature, humidity, pressing pressure, and addition of superplasticizer on the physical, mechanical, and thermal properties. *Case Studies in Construction Materials*, 19, e02529. <https://doi.org/10.1016/J.CSCM.2023.E02529>
- Zhou, Y., Dong, Z. Y., Hsieh, W. P., Goncharov, A. F., & Chen, X. J. (2022). Thermal conductivity of materials under pressure. *Nature Reviews Physics* 2022 4:5, 4(5), 319–335. <https://doi.org/10.1038/s42254-022-00423-9>