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ECONOMIC FEASIBILITY OF CALCINED KAOLIN USE IN THE PRODUCTION OF SPECIALIZED RUBBER TECHNICAL PRODUCTS

Oleksandr Lobach

Chairman of the Management Board TiMR S.P.Z.O.O, General Manager STANTON-ROCK LLC
Florida, USA

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ABSTRACT

The paper analyses the economic feasibility of integrating calcined kaolin into the production of specialised rubber technical products under conditions of price pressure, import dependence, and supply-chain restructuring. Relevance stems from the need to replace high-margin imported fillers with functionally adequate mineral alternatives that preserve product performance in demanding applications. The novelty of the study lies in combining a documented commercialisation case of a calcined kaolin grade introduced into a medical rubber-products manufacturer with recent scholarly evidence on kaolin-filled elastomer systems, clay modification, and calcination control. The aim is to determine under which technological and market conditions calcined kaolin becomes a rational material choice for specialised rubber compounds. The study applies comparative analysis, source synthesis, process interpretation, and analytical generalisation. The materials include recent journal papers on kaolin in styrene-butadiene and natural rubber systems, clay-modified binders, calcined kaolin reactivity, and adjacent speciality polymer applications. The results show that economic feasibility emerges from the combination of controlled filler functionality, lower procurement cost, acceptable processability, and application-specific rather than universal reinforcement targets

KEYWORDS: calcined kaolin, rubber compounds, specialised rubber products, mineral fillers.

1. INTRODUCTION

Specialised rubber technical products are produced under stricter material-selection constraints than mass-market elastomer goods. In such formulations, the choice of filler is tied to mechanical stability, curing behaviour, barrier response, heat build-up, process viscosity, and the predictability of industrial supply. When imported functional fillers become expensive or logistically unstable, the economic question shifts from simple procurement to the broader relation between material engineering and product viability.

Calcined kaolin occupies an intermediate position among mineral fillers. It does not compete with premium reinforcing systems in every formulation, yet in several industrial settings it offers a workable balance between cost, process behaviour, and performance. That balance becomes especially relevant when the target is not the maximum attainable reinforcement but reliable operation in a defined service regime, such as medical rubber goods, road-related elastomeric applications, protective compounds, or wear-sensitive products.

The study aims to determine the economic feasibility of using calcined kaolin in the production of specialised rubber technical products. To achieve this aim, three tasks are addressed: first, to identify the technological properties of calcined or modified kaolin that influence its suitability for elastomer compounding; second, to reconstruct the commercialisation logic of a practical market-entry case built around the Novacoat grade; third, to assess the conditions under which calcined kaolin becomes economically preferable to imported alternatives in specialised applications.

The scientific novelty lies in linking a concrete commercialisation trajectory with current academic evidence on kaolin-containing rubber and adjacent polymer systems. Rather than treating calcined kaolin as a generic mineral additive, the paper interprets it as a functionally tuned filler whose value depends on calcination regime, dispersion pathway, matrix compatibility, and the economic structure of the target market.

2. MATERIALS AND METHODS

2.1 Materials

The analytical base combines recent studies on kaolin-filled rubber systems, clay-modified elastomer-related materials, calcined kaolin processing, and speciality polymer applications. S. Li, Q. Liu, H. Wang, J. Wang, L. He, and S. Wu [1] investigated kaolin and sepiolite in rubber-modified asphalt and showed how clay additives affect emissions and rheological performance in rubber-containing road materials. H. Liu, K. Xiao, Y. Zhang, Y. Gong, and Y. Zhang [2] examined kaolinite-supported cerium oxide in styrene-butadiene rubber and clarified the relation between kaolin-based filler design, ageing resistance, and mechanical behavior. A. Marinelli, M. V. Diamanti, M. Pedeferri, and B. Del Curto [3] studied kaolin-filled styrene-butadiene dispersion systems and provided evidence on barrier performance in a styrene-butadiene matrix outside classical tire compounding. Nasruddin, W. B. Setianto, Lanjar, P. Atmaji, S. Agustini, Rienoviar, E. P. Wulandari, T. I. Sari, and B. Ibrahim [4] analyzed a lower-cost mineral filler/plasticizer substitute in rubber compounds, which is informative for the economic logic of filler replacement. T. M. Ragi, A. Francy, A. P. Mohamed, and S. Ananthakumar [5] demonstrated how kaolin micro-composite fillers can be engineered for specialty polymer applications requiring durability and surface-functional performance. S. Vigneswaran, J. Yun, H. Kim, M. D. Amiri, and S.-J. Lee [6] assessed clay-modified rubberized binders and highlighted the processing consequences of kaolinite in rubber-containing systems. Y. Xiao, Z. Xu,

C. Wang, and H. Bian [7] proposed a kaolin modification route for natural rubber composites and emphasized dispersion improvement and barrier-related gains. Y. Xiao, B. Li, Y. Huang, Z. Gong, P. Diao, C. Wang, and H. Bian [8] examined wet mixing of kaolin in natural rubber and showed how kaolin participates in low-heat-generation and wear-resistant formulations. H. Yin, H. Liu, Y. Bu, W. Chen, F. Ding, W. Lin, and Y. Zhang [9] analysed the reactivity of calcined ultrafine kaolin products and identified calcination parameters that determine downstream functionality. K. Yu, X. Shang, L. Fu, X. Zuo, and H. Yang [10] summarised broader performance patterns of clay-mineral composites, which helps place kaolin use within a wider family of application-specific mineral reinforcement strategies.

2.2 Methods

The study uses comparative analysis, source analysis, conceptual structuring, analytical synthesis, and case-based interpretation. These methods were selected to connect the material science of kaolin transformation with the commercial logic of filler substitution and to evaluate economic feasibility through the interaction of price, processing, and application fit.

3. RESULTS

Economic feasibility in specialised rubber compounding cannot be reduced to a single factor, such as a lower filler price. In elastomer systems, a cheaper mineral becomes commercially relevant only when it preserves enough functional adequacy to keep the final product within its service envelope. Recent studies show that kaolin-based systems perform best when three variables are aligned: the structural state of the filler, its dispersion route, and the performance target of the compound. In styrene-butadiene rubber, kaolinite-derived fillers are associated with improved ageing resistance and mechanical stabilisation when the filler surface participates in more effective matrix interaction [2]. In natural rubber systems, kaolin modification and wet-mixing strategies improve dispersion, barrier behaviour, and wear-related performance, which changes the evaluation criterion from absolute reinforcement to performance-per-cost efficiency [7, 8]. More broadly, clay-based composite studies indicate that matrix compatibility and processing route determine whether a mineral filler acts as a passive diluent or as a functional component of the composite structure [10].

For calcined kaolin, the production route is decisive. The literature on ultrafine calcined kaolin confirms that calcination temperature, holding time, and phase evolution govern the product's reactivity and, consequently, its usefulness in downstream formulations [9]. That point matters directly for specialised rubber goods. A material supplied as a generic metakaolin-grade powder for construction use does not automatically fit elastomer compounding, because the economic value of a filler in rubber depends on more than aluminosilicate composition. It depends on particle behaviour during mixing, compatibility with the curing system, and its effect on the balance between stiffness,

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resilience, wear, and processing stability.

The practical case reconstructed in this paper follows that logic. In 2019, market analysis of imported high-margin materials for Ukrainian industrial buyers revealed a price corridor of about EUR 1100–1200 per metric ton for imported calcined kaolin intended for demanding formulations. A lower-cost entry was sought without reducing the functional quality required by downstream producers. During negotiations at Indian Ceramic 2019 and subsequent visits to two Indian producers, the project moved from trading logic to technological adaptation. One of the potential partners had suitable equipment but was focused on metakaolin for construction mixtures rather than on a grade optimised for specialised industrial compounding. The commercial opportunity, therefore, depended on process correction rather than on simple resale.

At that stage, the economic problem became inseparable from process engineering. The transition to the Novacoat grade was achieved by adjusting kiln temperature regimes and the time cycles in the firing and cooling chambers. From an analytical standpoint, this sequence closely matches the mechanism described in current research on calcined kaolin reactivity: altered thermal treatment alters the degree of dehydroxylation and the functional state of the mineral, thereby affecting its downstream behaviour [9]. What emerged from the case was not a mere sourcing alternative, but a technically tuned filler positioned between conventional metakaolin and a more application-directed calcined kaolin product.

Two linked decisions strengthened the commercial result. First, exclusive sales rights for the Ukrainian territory were obtained. Second, the product reached a concrete industrial destination rather than remaining a speculative warehouse item. The Novacoat grade was introduced at Kyivguma, a manufacturer of specialised rubber technical products for medical use. That step is economically significant because qualification by a demanding producer reduces the market uncertainty that often undermines lower-cost mineral substitutes. A price advantage, by itself, rarely secures adoption in specialised elastomer goods. Industrial entry becomes realistic when the filler passes from nominal equivalence to application-tested adequacy.

A second layer of economic feasibility arises from the formulation purpose. The literature does not support treating kaolin as a universal replacement for premium reinforcing fillers across all rubber products. Instead, it promotes selective use in systems were barrier response, heat management, wear profile, rheological moderation, surface durability, or emissions behaviour matter alongside classical strength indicators. Modified kaolin in natural rubber improves gas-barrier-related behaviour and overall composite performance when dispersion is intensified through ball milling and spray drying [7]. Wet-mixed kaolin/silica systems are linked with reduced rolling resistance, better wear resistance, and lower heat generation in natural rubber [8]. In rubberised binders, kaolinite influences viscosity and road-performance metrics [6], while kaolin-containing mineral systems in asphalt environments suppress harmful fumes and improve compatibility under high-temperature processing [1]. Even in adjacent polymer fields, kaolin is used where speciality performance must be achieved through a mineral route that remains scalable and materially available [3, 5]. This body of evidence supports an application-led model of economic rationality.

The Novacoat trajectory fits exactly such a model. Its feasibility did not rest on claiming that calcined kaolin outperforms every alternative filler. It rested on delivering sufficient functionality for a specific class of rubber products at a materially lower entry price than imported analogues. In economic terms, the filler created value through avoided import premiums, localised distribution control, and closer alignment with the needs of downstream processors. Strategically, it reduced dependence on a narrow external supplier base in a market already exposed to regional disruptions.

The case also gains weight from an earlier institutional precedent. Between 2006 and 2017, work on kaolin extraction, beneficiation, and bleaching in Ukraine led to the introduction of DniproGloss and DniproCoat grades based on a kaolin separation/bleaching know-how developed at the former chemical bleaching unit of Prosyansky GOK and later Prosko-Resursy. That earlier experience had already shown that mineral raw materials can move from commodity circulation into high-margin segments when process control is used to satisfy a neglected market niche. In the present article, precedent matters because it shows organisational continuity in identifying market gaps through mineral-processing capability rather than through price arbitrage alone.

The technological-commercial relation outlined above can be summarised schematically (see Fig. 1).

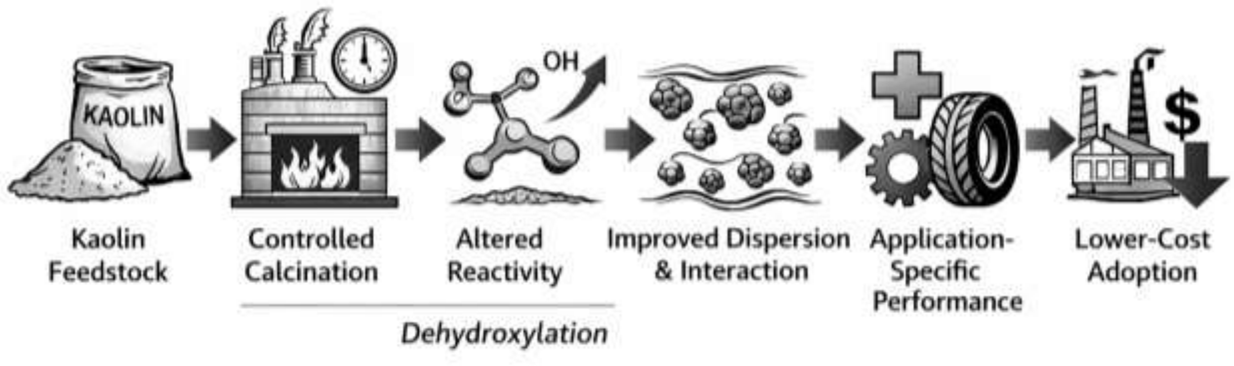

Figure 1: Analytical pathway from calcination control to economic feasibility in specialised rubber compounding (adapted from [9])

The broader implication of the case is that calcined kaolin becomes economically feasible in specialised rubber production when four conditions coincide: a visible import premium on incumbent products; the ability to tune calcination and post-calcination behaviour toward an elastomer-compatible grade; verified performance within a specific industrial application; and a distribution model that converts technical adaptation into secure market access. Where one of these conditions is missing, calcined kaolin remains a plausible laboratory material but an uncertain commercial proposition.

4. DISCUSSION

The analytical findings indicate that the value of calcined kaolin in specialised rubber production is best understood through a differentiated filler strategy rather than through one-to-one substitution logic. The literature points to several domains in which kaolin-based systems offer economically attractive property packages, yet the mechanism differs from case to case. Table 1 summarises how recent studies frame diversity.

Table 1: Functional-economic positions of kaolin-based fillers across rubber-related systems

System	Reported material effect	Economic reading	Relevance to specialised rubber products
Rubber-modified asphalt with kaolin/sepiolite [1]	Fume suppression, rheological adjustment, compatibility effects	Reduces process-related externalities in high-temperature mixing	Relevant for road-contact and infrastructure-oriented elastomer systems
Styrene-butadiene rubber with kaolinite-supported filler [2]	Better ageing resistance and mechanical stabilisation	Supports longer service life where durability offsets filler-cost sensitivity	Relevant for service-critical formulations
Styrene-butadiene dispersion systems with kaolin [3]	Improved barrier performance at selected loadings	Shows that kaolin can add functional value in SBR-based matrices beyond classical reinforcement	Relevant for seal-forming and barrier-sensitive products
Alternative mineral filler/plasticiser in rubber compounds [4]	Lower-cost substitution route with acceptable product fit	Confirms market pressure toward mineral replacements when performance thresholds are met	Relevant for cost-controlled industrial compounds

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Kaolin micro-composite fillers in speciality polymers [5]	Surface durability and functional enhancement	Demonstrates that mineral engineering can open high-value speciality niches	Relevant for rubber goods requiring added surface or thermal stability
Clay-modified rubberised binders [6]	Viscosity and performance adjustments depending on clay type	Processing behaviour enters economic evaluation alongside end-use properties	Relevant for compounds where the mixing window is commercially sensitive
Modified kaolin in natural rubber [7]	Better dispersion, barrier response, and overall composite behaviour	Functional gains raise the value of kaolin beyond simple dilution	Relevant for tailored formulations
Wet-mixed kaolin/silica natural rubber [8]	Lower heat generation and better wear response	Feasibility rises when kaolin improves the performance-to-cost ratio	Relevant for dynamic-load applications
Controlled calcined ultrafine kaolin [9]	Reactivity governed by calcination parameters	Process control is a pricing lever because it determines downstream usefulness	Relevant for the commercialisation of calcined kaolin grades
Review of clay-mineral tribo-composites [10]	Performance depends on the matrix, modification, and synthesis route	Application fit, rather than filler identity alone, determines value capture	Relevant for friction-sensitive and wear-driven rubber systems

Table 1 shows why a narrow comparison between calcined kaolin and conventional premium fillers is analytically weak. Kaolin becomes commercially viable when the target formulation benefits from thermal moderation, barrier improvement, process control, durability, or wear behaviour. Under such conditions, the economically correct question concerns the minimum functional threshold required by the product, not the theoretical maximum reinforcement reachable by another filler system. That distinction explains why the Novacoat route was viable for specialised rubber goods even without claiming universal superiority.

A second issue concerns the structure of the decision itself. The present article relies on a documented implementation case and published material-science studies, yet no plant-wide cost sheet, cure-kinetics dataset, or long-run failure statistics are available. For that reason, the assessment remains analytical rather than experimental. Still, the literature allows identification of recurrent conditions under which mineral-filler substitution becomes commercially viable. These conditions are summarised in Table 2.

Table 2: Analytical conditions for economically justified use of calcined kaolin in specialised rubber compounds

Decision condition	*Literature-based interpretation*	*Economic implication*
Imported incumbent filler is priced as a speciality product [4, 9]	Market entry becomes plausible when an alternative grade can be delivered with a lower procurement burden	Savings arise before compounding begins
Filler functionality can be tuned through calcination or modification [7, 8, 9]	Material value depends on controlled structure, reactivity, and dispersion behaviour	Process engineering converts raw minerals into commercial differentiation
Matrix compatibility is application-specific rather than universal [2, 3, 10]	Kaolin is rational where the product requires adequate, not maximal, reinforcement	Feasibility depends on formulation target, not on generic filler rankings
Processing constraints affect cost and adoption [1, 6, 8]	Viscosity window, emissions, and mixing behaviour alter qualification risk and production expense	Lower technical friction accelerates industrial acceptance
Speciality applications reward tailored mineral systems [3, 5, 10]	High-value niches are open to mineral fillers when they add a defined functional benefit	Commercial margins depend on fit-for-purpose performance

Table 2 clarifies the commercial logic of the Novacoat case. The decisive move was the conversion of a construction-oriented mineral-processing line into a supply route for a more demanding industrial application. The economic gain, therefore, came from three linked layers: a lower entry price than imported calcined kaolin, a technically adapted filler state, and a verified destination in specialised medical rubber production. Without the second and third layers, the first would have remained a temporary discount rather than a durable market position.

The limitations of the analytical format should be stated directly. The study does not provide a side-by-side plant trial against all competing fillers, nor does it quantify full lifecycle cost, scrap reduction, or long-term field failure. As a result, the conclusions are constrained by process logic, documented commercialisation evidence, and published studies on related kaolin-based systems. Yet this limitation does not weaken the central inference. It simply narrows it: calcined kaolin should be treated as a strategically engineered filler for selective, specialised rubber applications, not as a universal replacement category.

For industrial practice, the applied implication is clear. Where a producer faces high import costs, unstable logistics, or the need to qualify a technically acceptable but more economical filler, calcined kaolin becomes a rational option if the grade is tuned to the formulation and validated in the target product class. In that sense, the economic feasibility of calcined kaolin is created through process adaptation and market alignment rather than through raw-mineral availability alone.

5. CONCLUSION

The study established that the feasibility of using calcined kaolin in specialised rubber technical products depends on the interaction between material engineering and market conditions. The first task showed that the commercial value of calcined kaolin is shaped by calcination regime, reactivity, dispersion pathway, and compatibility with the rubber matrix. The filler becomes relevant where the formulation rewards controlled processability, barrier response, heat moderation, wear profile, or service stability.

The second task reconstructed the Novacoat commercialisation route as a sequence in which price analysis, supplier negotiations, thermal-process correction, territorial exclusivity, and first industrial qualification formed a single economic mechanism. The case confirms that a lower-cost mineral route becomes sustainable only when the material is adapted to the product logic of the downstream user.
The third task demonstrated that calcined kaolin becomes economically preferable under selective rather than universal conditions. The strongest rationale emerges when imported speciality fillers are expensive, supply structures are unstable, and the target product requires fit-for-purpose performance rather than maximal reinforcement. Under these conditions, calcined kaolin serves as an engineered cost-performance solution that supports import substitution and market repositioning in specialised rubber production.

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