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SYNTHESIS AND UTILIZING NANOPOROUS MATERIAL FROM PARTIALLY LATERISED KHONDALITE ROCK FOR CORROSION STUDIES

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ABSTRACT

Partially Laterised Khondalite (PLK) rocks are a bauxite mining waste generated during the mining of the bauxite for the production of alumina. This waste can be transformed into a nanoporous material after a suitable physical beneficiation followed by a chemical activation process. In this paper, the nanoporous material was synthesized from the partially laterised khondalite (PLK) rocks, which was applied to a mild steel in the medium of hydrochloric acid of one molar (1 M) concentration. The characterisation study has been carried out on the raw material and the nanoporous material. The characterisation study included XRD, FTIR, SEM, TEM, BET. It was observed that the structural transformation occurs with an increase in surface area from 8.4 m^2/g to 162.7 m^2/g. The different experiments were carried out to reveal that the material acts as an efficient corrosion inhibitor by using electrochemical impedance spectroscopy (EIS), potentiodynamic polarization, and weight-loss experiments. It is found that the maximum inhibition efficiency of 92.5% achieved after dipping in the sea water for 72 hours. The resulting material improves performance and environmental impact while providing a more economical and sustainable option for creating anticorrosive coatings.

Keywords: *PLK, Nano-Porous, Characterisation, Valuable material, Corrosion.*

1. INTRODUCTION

A valuable mineral or metal can be extracted from the naturally occurring solid material known as bauxite, which is an ore of aluminum. The Palpachpatmali Hills in the Koraput district of Odisha are the source of the Bauxite Ore. This fully automated opencast mine has been in working since November 1985, providing feedstock to the foothills-based Damanjodi Alumina Refinery. Mines currently have a 68.25 lakh TPA capacity. Over 6.3 million tons of bauxite are mined annually by NALCO. A nearly equal quantity of partially laterized khondalite (PLK) rocks connected to kaolinized khondalite rocks are left unmined during the bauxite mining process. These PLK rocks are connected to the bottom bauxite in these mines. PLK is located beneath the bauxite mineral in the Panchapatmali mines. Owing to its elevated silica content, aluminum silicate is not mined and cannot be processed profitably to create metallurgical grade alumina. Partially laterized khondalite (PLK) consists mainly of alumina (35–45%), with

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smaller proportions of alumino-silicate minerals such as kaolinite and gibbsite (up to 15%), along with titanium- and iron-bearing minerals like hematite and goethite (10–20%).This rock is important for a variety of industrial uses because it primarily consists of the aluminum resource minerals gibbsite, sillimanite, and kaolinite, along with smaller amounts of goethite, hematite, quartz, and anatase. The PLK rock extracted from bauxite mines is put through a several processes, including crushing and grinding, to produce fine particles (less than 75 µm), which are then utilized in the experiment. The overflow sample obtained after hydrocyclone processing was used for the synthesis of nanoporous material from Partially Laterised Khondalite (PLK) rock. The nanoporous material produced from PLK can be used to create self-healing and anticorrosive coatings. Nanoporous material has a unique structure with a high surface area and the ability to absorb moisture and ions. This makes it useful for preventing corrosion, serving as a corrosion inhibitor, and for water treatment by absorbing contaminants and reducing humidity-related damage. In Corrosion Inhibitors, Nanoporous material can act as corrosion inhibitors by trapping moisture and metal ions that might otherwise contribute to the corrosion process. They can be incorporated into coatings or protective treatments for metal surfaces to reduce the risk of corrosion. In water treatment systems, Nanoporous material are used to filter out harmful ions and contaminants that could contribute to corrosion in pipes or equipment. By softening water and removing excess minerals like calcium and magnesium and Nanoporous material can help to reduce scaling and corrosion inside water systems. By Absorbing Contaminants, Nanoporous material can absorb harmful gases, like sulfur compounds or ammonia, which are known to promote corrosion. By removing these gases from the environment, they help protect metal surfaces from corrosion. In packaging or storage, Nanoporous material can be used as desiccants to control humidity levels, reducing the risk of corrosion caused by excess moisture. So, in essence, Nanoporous material help prevent corrosion by controlling moisture, absorbing harmful ions, and serving as a protective barrier in different industrial applications.

Over the past few years, several studies and fact-finding projects pertaining to review for synthesis of nanoporous through different processes are done.

Sergiy et al. (2024) article explores the growing use of zeolites as environmentally safe anticorrosion pigments in organic coatings for metals. The increased interest in zeolite-based pigments stems from the need to replace harmful chromates and reduce phosphate-based corrosion inhibitors. A review of existing literature evaluates the corrosion-inhibiting properties of zeolite pigments produced by various methods.

Chandrabhan et al. (2023) addresses the growing demand for effective and cost-efficient anticorrosive solutions, which have the potential to save billions annually by reducing corrosion-related costs. A key focus is on zeolites, which are used in anticorrosive and self-healing coatings. These zeolite-based coatings help prevent corrosion by forming protective oxide films (passivation) when defects occur. green synthesis techniques offer a more sustainable and economically viable alternative for producing zeolite-based anticorrosive coatings, enhancing both performance and environmental impact.

Devaki et al. (2023) investigates the use of zeolite as an environmentally friendly alternative to traditional corrosion-resistant coatings made from hard chrome, cadmium, and epoxy polymers for steel, magnesium, and aluminum alloys. Due to its inert nature, low modulus of elasticity, and high strength, zeolite is emerging as a promising material for anticorrosive coatings on metallic substrates.

Virendra et al. (2021) reviewed different papers on the utilization of incense stick ash for the production of zeolites. Zeolites are in demand in many industries like chemical, Petrochemical and wastewater industries but the production of zeolites using commercial methods is very expensive. So, incense stick ash is a waste product containing aluminosilicate and could act as a prospective source for the production of zeolites. The zeolites produced from incense stick ash are low budget, well-founded and ecological. The production of zeolites can reduce the problem associated with its disposal in water bodies and also reduce solid waste.

Virendra et al. (2021) demonstrated the production of Ca-based Zeolite from incense stick waste. Zeolites obtained are chemically characterized and identified by PSA, FTIR, XRD, FESEM, EDS, TEM and XRF. The produced zeolites are microporous and crystalline in nature and used as an adsorbent substance for correcting the contaminants present in water. Zeolites produced from incense stick ash can improve both heavy and alkali metals from wastewater.

Mahima et al. (2022) studied the production of zeolites A and zeolites X by using Indian coal fly ash in a hydrothermal process. The fly ash is transformed into zeolites A and Zeolites X through Nepheline as the intermediate phase. The produced zeolite is chemically characterized by XRD, FTIR, TG-DTA, SEM and BET. The BET method is used to determine the surface area of the produced products. The TG-DTA shows the transformation of nano-crystalline to micro-crystalline zeolites with the deficit of adsorbed water.

Daniela et al. (2021) explain the production and characterization of Na-P1 Zeolite by using Kaolinitic Clay by hydrothermal process. The kaolin clay is used for the production of zeolites due to its availability and its reaction with alkali. The process is beneficial as there is no use of additives and it also reduced temperature and production time. The characterization of the product is done by XRD, SEM, IR and ICP-OES. The Authors also compared results with previous papers on the synthesis of zeolites and suggest this process has wide applications for industries transfer.

Daniela et al. (2021) demonstrated the production of Analcime Zeolite by using Kaolinitic Clay and also studied its characterization. The process is carried out by hydrothermal method and without ageing times and without the use of Sodium silicate and additional Silica and Analcime is produced. Analcime is characterized by XRD, SEM, IR, ICP-OES and thermal analysis. The physical and chemical characteristics are satisfied making wide applications for industrial transfer.

Lukasz et al. (2021) studied the Mineralogical, Geochemical, and Rock Mechanic Characteristics of Zeolite-Bearing Rocks of the Hatrurim Basin, Israel. Meteoric water was interacting with Portland-cement-like rocks of the Hatrurim Complex to produce an alkaline environment that resulted in zeolitization. It results in 20-30% zeolitic material in the zeolite-bearing rocks. In the Levant desert climate, the natural zeolite-bearing rocks resist weathering.

Paulina et al. (2021) investigated on Production of Zeolites from Low-Quality Coal Fly Ash (CFA) and Wet Flue Gas Desulphurization Wastewater and its characterization. The characterization properties like mineralogical, chemical and textural properties were determined by XRD, XRF, SEM and CEC. The zeolites produced resulted in greater or comparable sorption properties and also can remove cationic and anionic compounds. Zeolites produced have properties that show they can be used as an adsorbent in industries.

Bin et al (2021) explained the production of K-based zeolites and also its characterization and thermodynamic study. The objective is to find out the thermodynamic data of 14 types of K-based zeolites. The zeolites are produced by the hydrothermal process and exchanged with K+ and characterization like XRD, FTIR, SEM-EDS and TGA are determined. The zeolites obtained provides data for the formation process of K-based zeolites in the content of cement and also in any environment.

Victor Peter Maciver et al. (2020) explains the process of production of zeolite X from kaolin clay from Kono-boue and Chokocho, river state, Nigeria. A Different process like beneficiation and calcination of raw kaolin is done to convert into reactive metakaolin. The Hydrothermal process was demonstrated to produce industrial catalyst zeolite from the locally sourced catalyst. Chemical characterization of crystalline phase was identified by XRD, XRF, EDS, SEM and FTIR. Both chokocho and kono-boue confirmed the presence of zeolitic mineral phase but the chokocho sample was more crystalline with larger sharper peaks than kono-boue. The appearance of higher silica to alumina ratios of 10.73 and 14.36 after treatments in XRF and the EDS exhibit the absence of some toxic metals signify that the zeolites produced were both safe and environmentally friendly.

Guojun ke et al. (2019) produces X-zeolite from waste Basalt powder. Two methods that are Traditional Hydrothermal method (TH) and Alkali Fusion assisted Hydrothermal method (AFH) were executed for the preparation of zeolite and also using NaOH as an activation reagent. The X-zeolite produced was characterized by Acid treatment, alkali/basalt ratio, calcination temperature and crystallization temperature play a vital role in the formation of zeolites from basalt. The acid treatment increases the yield and quality of zeolites. The quality and type of zeolite produced can vary considerably depending upon formation conditions and parameters. The study shows that zeolite can be prepared by using basalt as a raw material.

Sagar Kumar Nayak et al. (2019) studied the Retrospective synthesis of zeolite from waste and its applications. Both natural zeolite and synthetic zeolite have various applications without any harm to the environment. The synthetic zeolite as molecular sieves have several applications like it can be used in water treatment, agriculture, biomedical engineering, and petroleum refining process. Zeolites can also be synthesized from wastes like fly ash, blast furnace slag, rice husk ash, and kaolin etc. The natural zeolite should be utilize in the cement preparation, as filler in paper, an energy supplier in solar refrigerator etc. Research is going on to make zeolites user-friendly for the common man in various potential applications.

Eva Ujaczki et al. (2019) demonstrated the extractions of Gallium from bauxite residue using mineral acids (H_2SO_4, HCl, and HNO_3) and an organic acid ($H_2C_2O_4$—oxalic acid). As compared to other acids, oxalic acid has the highest Ga leaching efficiencies. This leaching experimental result was optimized by Experimental design (DOE) software for extraction Ga by Oxalic Acid. Then, studied the effects of adsorbent dosage, temperature, and contact time on the removal of Gallium by zeolite HY from synthetic Gallium solution . The achieved adsorption experimental results was created in the DOE model and yield a maximal Ga removal efficiency of 99.4%.

Tao Zhu et al. (2019) investigated the synthesis of zeolite X by aluminium residue obtained from coal fly ash and their applications for the adsorption of volatile organic compounds. The utilization of coal fly ash is discovered the resource for use of waste and also produce high environmental and social benefits. The production of zeolite X by hydrothermal synthesis method was of high purity and crystallinity through the analysis of the chemical phase. When estimating volatile organic compounds and activated carbon, it is found that the volatile organic compounds adsorption capacity exceeds the activated carbon and it has stronger stability. This adsorption of volatile organic compounds in the preparation of zeolite confirms environmental protection and energy-saving effect and has strong potential applications.

Dinh Thi Ngoc Quyen et al. (2017) investigated the synthesis of material with zeolite structure by fusion method from red mud and rice husk ash and by taking different ratios of red mud and rice husk ash, calcination temperature and calcination time. The synthesized materials were characterized by XRD, SEM, BET and CO_2 adsorption capacity. The resulted sample was treated at 600° C for 2 hours with the ratio of SiO_2/Al_2O_3 of 1.8 had the best adsorption capacity.

Ranjita Swain et al. (2018) looked at the industrial uses of a useful chemical that is produced during bauxite mining. Hydrocyclone divides PLK samples into overflow and underflow categories. These conditions—a vortex finder with a diameter of 11.1 mm and an 8.0 mm spigot diameter that enhances feed capacity—are ideal for recovering tiny particles from the PLK rock sample. The overflow sample is utilized as a raw material in the ceramic and cosmetic industries, while the underflow sample is suitable for use in the production of refractory applications.

Ranjita Swain et al. (2014) investigated the use of thermal shock resistance as a means of energy conservation and preservation on partially lateralized khondalite rock. For size reduction and grain boundary breaking, thermal shock treatment is used. The granulating characteristics of partially laterized Khondalite rock and the total energy obtained for thermal shock treatment are the main topics of this paper. A specimen achieves 52.8% of its total energy after sixty minutes of warming at 1123 K.

In this investigation, the PLK sample was used for the synthesis of nanoporous material. The product characterization study is being assessed and contrasted. The goal of the current work is to recover PLK rock and use it to create value-added materials. This study discusses the synthesis of zeolite, a nanoporous material, from PLK rock samples and further its use for application as corrosion study to create coatings that are self-healing and anticorrosive. A physicochemical examination of the hydrocyclone sample was performed. Additional characterization research was done on the overflow sample. Characterization techniques include XRF, TEM, SEM, FTIR, and XRD. According to certain literature, the iron content of the PLK sample could not be separated using gravitational or magnetic separation techniques. This is because the sample was prepared for physical beneficiation research. For this reason, the majority of leaching reaction procedures are employed to extract iron from the sample and recover useful components. The primary goal is that PLK has the potential to be a resource for a variety of industries where it could be an inventive way to produce nanoporous material. The nano porous material obtained from PLK is used as a coating to prevent corrosion. So, nonporous material was synthesized from PLK rock and the used for coating as a barrier to prevent corrosion.

2. EXPERIMENT

A sample of partially laterized khondalite rocks was taken from the Damanjodi NALCO Bauxite Mining Area. The PLK rock sample was crushed into a 2 mm size using a jaw crusher and a roll crusher. The sample that was crushed was ground smaller than 75µm. The ground material was then divided into two portions using Hydrocyclone. Fig. 1 displays the sample preparation schematic diagram. A physicochemical examination of the hydrocyclone sample was performed. Additional characterization research was done on the overflow sample. The XRD, SEM, TEM, and FTIR are used in the characterization. The Bruker D8 Advance and Bruker D8 Advance Twin-Twin are used for X-ray analysis. Jeol 6390LA SEM is used, with the following specifications: element mapping, tungsten filament, 0.5 to 30 kV

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acceleration voltage, 136 eV EDAX resolution, and 30 mm2 EDAX detector area. Jeol 200kV, point resolution 0.23 nm, and lattice resolution 0.14 nm are used for TEM examination. Thermo Nicolet iS50 4000 cm-1 to 100cm-1, Resolution 0.2 cm-1, S/N Ratio 55,000:1, ATR-Diamond crystal, Liquid Cell, and Gas Cell attachments are used in FTIR analysis.

Nanoporous material is synthesised by taking a sample of partially laterized khondalite rock and mixed with a 1:2 solution of Sodium Hydroxide. The sample was then maintained for one hour at temperature. Filter paper was used to wash the sample in order to eliminate any excess Sodium Hydroxide, and the resulting solution was then used for further processing. The solution was continually stirred while being maintained at 70 ℃ on a hot plate. The sample is titrated with chemical and stirring is done. After filtering the sample, agitate it once more until a white precipitate appears. The sample receives from precipitation is dried and sample is characterised. Incorporated into coatings as a direct additive or combined with binders, nanoporous materials offer as a layer to prevent corrosion. The nanoporous substance adhere to the metal surface with the aid of a binder, creating a strong, protective covering. Epoxy resin is the binder utilized here as Coatings based on epoxy are frequently employed as binders to keep the particles together, improve adherence to metal surfaces, and provide extra corrosion protection.

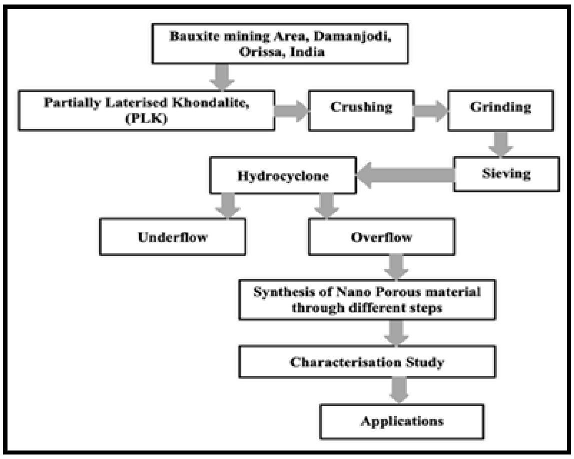

Fig. 1. Flowsheet development for recovery of industrial material from PLK rocks

Table 1- Process Parameters for synthesis of Nanoporous material from PLK sample

Parameters	Values
Composition of Sample, gm	10
Reaction time, minutes	240
Reaction temperature, ºC	70
Solid-to-solid ratio	1:2
Stirring speed, rpm,	300
pH	10

Since mild steel is one of the most often utilized steel kinds because of its strength, adaptability, and affordability, it is employed for corrosion investigations. Among the various industries that employ mild steel are construction (for beams, columns, and reinforcements), automotive (for machinery tools), and general fabrication (for pipes, wire, and structural elements). Particularly in settings with moisture, salt, or acids, mild steel is prone to corrosion. Coatings, however, can be used to control this and stop corrosion. When compared to other kinds of steel or metals, mild steel is comparatively cheap. This is one of the reasons it's utilized in so many different industries, including as manufacturing, automotive, and construction. Total four Mild Steel is taken of 1inch each and two are coated uniformly and dried for 24hrs.

Volume of mild steel = Length* Width*Depth = 2.54 * 1.52* 0.76 cm^3 = 0.0254 * 0.0152 * 0.0076 m^3= 2.934 cm^3

Density of mild steel is 7.85 grams per cubic centimeter (g/cm^3) or 7860 kilograms per cubic meter (kg/m^3).

Now, Weight = Volume * Density
= 2.934 * 7.85
= 23.03 gm of each mild steel is taken for corrosion study purposes.

100 millilitres of distilled water and 1000 millilitres of seawater were gathered from Puri Beach in Odisha. One inch of mild steel, weighing 23.03 grams each, was extracted. In a tightly sealed stopper, the coated and rust-free mild steel is submerged in water at a temperature of 30°C for different hours. The sample was weighted at different intervals i.e. 24 hours, 48 hours and 72 hours, and the result was calculated. Weight loss can be detected by using the above method on the coated steel sample. The EIS measurement was carried out in a range of 10 mHz–100 kHz. Potentiometer polarisation scanned at a rate of 1 mV/s. The inhibitor concentration was tested in the range 0-800 mg/L.

3. RESULTS AND DISCUSSION

The data is shown in the Table.2 indicates the hydrocyclone overflow sample has 38.9% Al_2O_3, 4.5% Fe_2O_3, and 39.9% SiO_2. According to the statistics, the true density is 2.2 g/cm^3, but the bulk density is 1.7 g/cm^3. The angle of repose is 34.5°, while the porosity is determined at 49.0%. The nanoporous material contains 46.9% Al_2O_3, 0.8% Fe_2O_3, and 36.6% SiO_2. The presence of titanium dioxide indicates that the material might have uses in certain specialized applications, such as pigments or coatings.

Table 2 - Physicochemical analysis of raw materials of PLK rocks

Details	Physical Characteristics				
	Bulk Density, gm/cm^3	True Density	Porosity, %	Angle of Repose, °	
Hydrocyclone Overflow Sample	1.7	2.2	49.0	34.5	
Nanoporous material	1.1	2.1	70.0	33.7	
Details	**Chemical Characterization**				
	Al_2O_3 %	SiO_2 %	Fe_2O_3 %	TiO2, %	LOI, %
Hydrocyclone Overflow Sample	38.9	39.9	4.5	1.4	15.3
Nanoporous material	46.9	36.6	0.8	1.3	14.4

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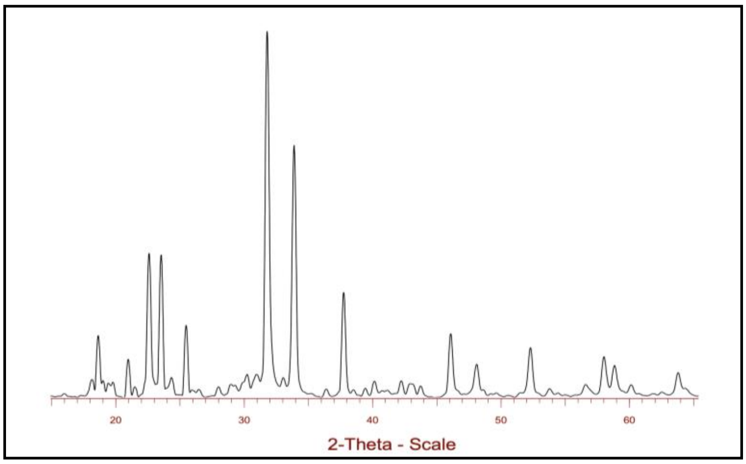

Fig.2: XRD pattern of nanoporous material

The patterns at a standard of 2 theta-scale range between 5 and 80 were determined using an XRD diffractometer. The calcined sample's XRD patterns are shown in Fig. 2. The findings show that the component phase crystal structure is the main product obtained, and the XRD data collected shows an increase in the intensities of the XRD peak.

The highest peak is showing kaolinite present in the nanoporous material. The other exhibited peaks are quartz, feldspar, and hematite. The crystallinity is decreased, partially amorphous in nature with typical of porous aluminosilicates.

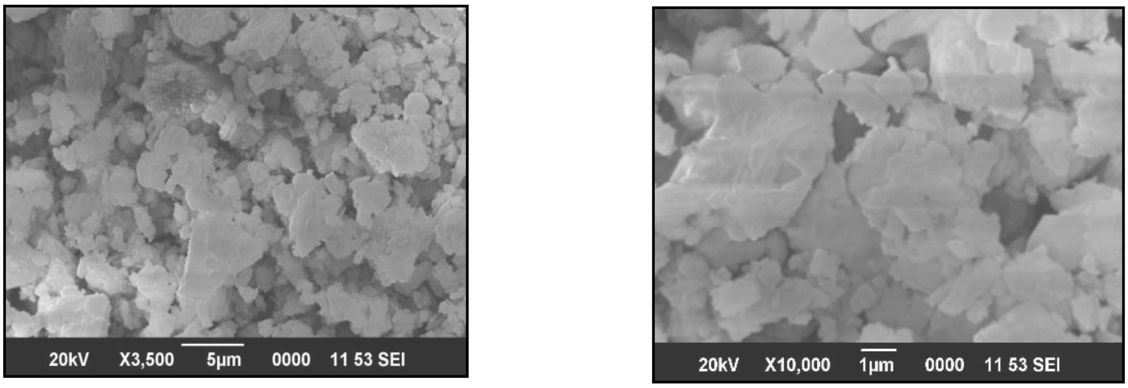

Fig.3: SEM pattern of nanoporous material

The size distribution and shape of the zeolite crystals were established by means of scanning electron microscopy. At 5μ SEM the crystal phase that results from precipitating nanoporous material is depicted μin Fig.3. Since the shape of individual crystals is well defined, the photomicrograph amply illustrates the change. Good surface morphology and a hexagon-shaped crystal lattice is indicated by SEM examination. The khondalite rocks has irregular, rough fracture surface whereas the microchannels are formed after activation.

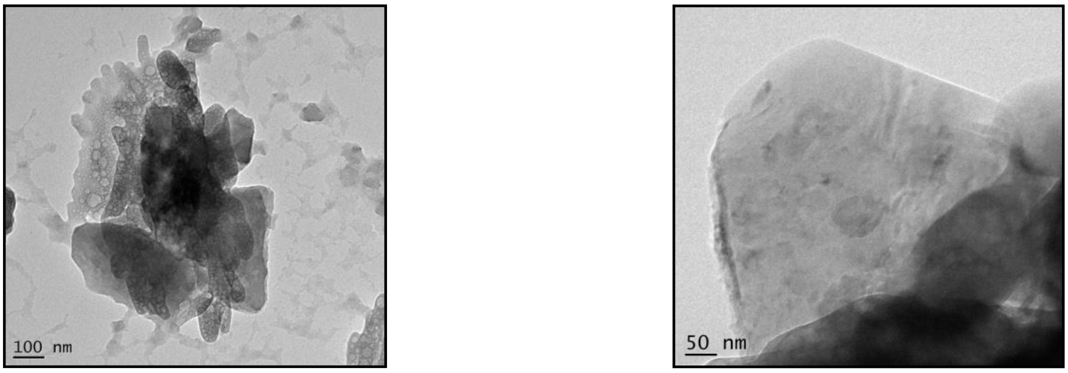

Fig.4: TEM pattern of nanoporous material

Transmission electron microscopy (TEM) provides information on internal structures of nano-materials obtained at different scales. TEM analyses the size, morphology, etc., of the structure. The TEM characterisation in Fig.4. confirms that the nano porous material lies in the nano-size range and are used to observe the shape and distribution of nanoporous particle. It shows the uniform mesoporous structure with a estimated pore diameters of 50-100 nm.

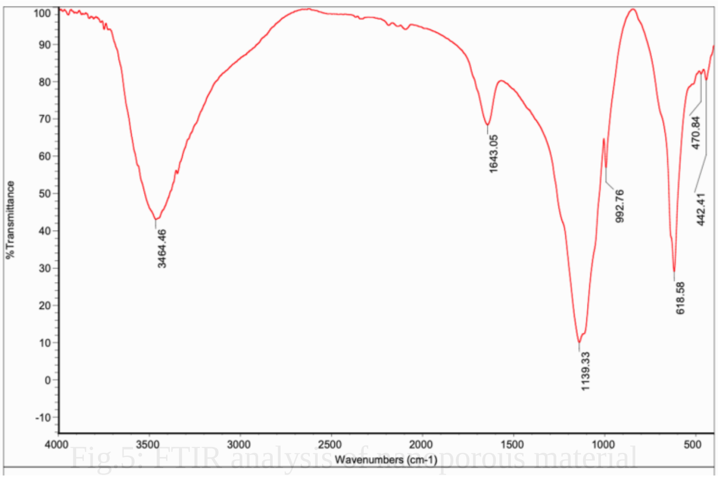

Fig.5: FTIR analysis of nanoporous material

FTIR (Fourier Transform Infrared) spectroscopy is a powerful technique used to analyze the chemical composition of materials by detecting the absorption of infrared light at various wavelengths. In the FTIR spectrum, the OH bands are observed as a single strong broad band occurring at approximately 3500 cm−1. These results can be seen in Fig. 5, representing the FTIR spectrum of sample. These strong broad bands can thus be attributed to the presence of hydroxyls group. The FTIR spectrum also shows strong medium bands at 1643 cm^{-1} respectively. These bands can be attributed to the H_2O deformation mode normally seen at 1650 cm^{-1}. The peaks are showing the presence of different minerals. For Corrosion prevention, the potential of nanoporous materials are helpful in improving corrosion resistance due to their unique properties such as high surface area, catalytic activity, and the ability to form protective coatings.

Table 4. BET surface area of the raw material and nanoporous material

Property	Hydrocyclone overflow sample	Nanoporous material
BET Surface Area (m^2/g)	298.8	320.5
Pore Volume (cm^3/g)	0.092	0.166
Average Pore Size (nm)	11.5	6.7

Table.4 shows the BET surface area is increased after the chemical activation of the sample. Table 5 shows that the weight loss of coated sample was less as compared with uncoated mild steel sample exposed to sea water. Nanoporous particles help form a dense and impermeable layer on the surface, preventing corrosive agents from reaching the substrate. Nanoporous materials have demonstrated remarkable potential in the field of corrosion prevention, offering innovative solutions that not only enhance the durability and performance of metals but also reduce environmental and maintenance costs.

Table5. Weight loss of sample exposed during different time intervals.

Sample	Weight loss after 24hrs	Weight loss after 48 hrs	Weight loss after 72 hrs	Inhibition efficiency after 72 hrs., %
Distilled water without coated Mild steel	0.737	1.032	1.578	-
Distilled water with Coated Mild Steel	0.002	0.021	0.456	71.1
Sea Beach water without Coated Mild Steel	1.456	1.825	2.356	
Sea Beach water with Coated Mild Steel	0.09	0.126	0.176	92.5

In Table. 5 the inhibition efficiency increases with salt water (sea water) due to increased surface coverage.

Table 6. Electrochemical Impedance Spectroscopy (EIS) test

Sample	Rct ($\Omega \cdot cm^2$)	Cdl ($\mu F/cm^2$)
Distilled water without coated Mild steel	23	328
Distilled water with Coated Mild Steel	75	244
Sea Beach water without Coated Mild Steel	119	181
Sea Beach water with Coated Mild Steel	203	122

The charge transfer resistance (Rct) value for the coated mild steel gives better result than the uncoated steel for both distilled water and sea water. Sea water shows more reactive but the coating is more effective in salty condition. The coating ability depends upon the R_{ct} and C_{dl} value for corrosion resistance. The value of the dipped steel shows the value in Rct in increasing that other material dipped in other solutions with coating gives reduce the value of active surface area and slows down the corrosion reaction which confirm from the increasing value of R_{ct} and decreasing value of C_{dl} value.

Table 7. Potentiodynamic Polarization Results of the coated and uncoated materials

Sample	i_{corr} (μA/cm²)	β_a (mV/dec)	β_c (mV/dec)
Sea Beach water without Coated Mild Steel	321	66	98
Sea Beach water with Coated Mild Steel	58	52	82

The value of corrosion current density (i_{corr}) for the uncoated mild steel shows the rate of corrosion is more than coated one due to the salt contact of sea water. Tefel slopes such as β_a and β_c are the anodic and cathodic reaction kinetics respectively that changes reflect the effect of coating on the electrochemical mechanism. The value indicates the moderate anodic slope that gives the active metal dissolution, but the higher cathodic value indicates that the rate of oxygen reduction. Both the results shows that the surface is active electrochemically with a little resistance. The uncoated material corrodes very fast due to the chloride effect. The i_{corr} decreases by 82% as compared to the uncoated material, rate of corrosion is less as the coating blocks the electrolyte penetration rate and restricts the anodic dissolution. Both the slopes decrease which indicates that the rate of dissolution and the reduction of oxygen decreases. These indicates the presence of a protective barrier layer that slows both reactions. i_{corr} reduced by 89%, which shows the excellent inhibition and both slopes gives the mixed type inhibitor.

4. CONCLUSIONS

The present study demonstrates the successful synthesis, characterization, and corrosion-inhibition performance of nanoporous material derived from Partially Laterised Khondalite (PLK) rock, a bauxite-mining waste generated in significant quantities in the Panchapatmali region of Odisha. Through a combination of physical beneficiation and chemical activation, PLK—originally considered an industrial reject—was transformed into a high-value nanoporous aluminosilicate with desirable textural and structural properties suitable for anticorrosive applications.

Comprehensive characterization of the synthesized material using XRD, FTIR, SEM, TEM, and BET analysis confirmed notable structural modifications following the activation process. The surface area increased sharply (from 8.4 m²/g to 162.7 m²/g), accompanied by the development of a partially amorphous, micro- to mesoporous morphology. SEM and TEM images showed well-formed hexagonal and micro-channel features, while XRD patterns indicated the presence of kaolinite, quartz, and feldspar with a decreased crystallinity typical of porous aluminosilicates. FTIR analysis confirmed hydroxyl and water deformation bands, further supporting the formation of active functional groups within the porous network. These properties collectively point toward a material capable of ion adsorption, moisture trapping, and surface passivation—characteristics highly advantageous in corrosion-inhibitor systems.

The corrosion studies performed on mild steel in both distilled and seawater media reveal that the nanoporous coating significantly enhances corrosion resistance. Weight-loss measurements showed a dramatic reduction in mass loss for coated samples, with inhibition efficiencies reaching 71.1% in distilled water and 92.5% in seawater after 72 hours. The superior performance in saline media indicates enhanced surface coverage and stronger barrier protection due to the interaction of chloride ions with the porous network, which likely promotes a more compact passive film.

Electrochemical Impedance Spectroscopy further confirmed improved corrosion resistance, as evidenced by the substantial increase in charge transfer resistance (Rct) and the corresponding decrease in double-layer capacitance (Cdl) for coated samples. These trends indicate reduced electroactive surface area, slower corrosion kinetics, and enhanced integrity of the protective coating. Potentiodynamic polarization studies showed an 82–89% reduction in corrosion current density (icorr) for the coated steel, demonstrating that the nanoporous material acts as a mixed-type inhibitor by suppressing both anodic dissolution and cathodic oxygen-reduction processes. The shift in Tafel slopes also highlights the formation of a stable barrier layer that impedes electrolyte penetration.

Overall, the findings confirm that PLK-derived nanoporous material is an efficient, eco-friendly, and low-cost corrosion inhibitor suitable for protective coatings. Its performance in aggressive environments, particularly seawater, highlights its potential for applications in marine, chemical-processing, and infrastructure sectors where corrosion challenges are severe. Beyond its functional properties, this research presents a sustainable waste-valorization approach by converting mining rejects into high-value materials, thereby minimizing environmental burden and promoting circular-economy practices. The promising outcomes of this study encourage further development of PLK-based nanoporous materials for advanced anticorrosive, adsorption, and surface-engineering applications.

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