Mineralogical and Optical Comparison of Kota Stone Slurry and Jarosite Residue: Implications for Waste Valorization

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Abstract: ***The rising accumulation of wastes generated by the industrial minerals sector requires sustainable solutions for characterisation, management and valorization. The two waste streams are limestone processing waste stream which is known as kota stone slurry and cement and jarosite which is a byproduct of zinc hydrometallurgical activities with different compositions and environmental characteristics. The present work comprised a complete comparative investigation of these materials by X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR) and UV visible spectroscopy to determine the structure property connections for sustainable applications. XRD data indicate that the Kota stone slurry is mostly composed of highly crystalline calcite phase with secondary contribution from quartz, whereas Jarosite residue has a sulfate rich crystalline structure with iron carrying crystalline phases. FTIR analysis was performed for identification of carbonate-silicate linkages in Kota stone slurry and sulfate hydroxyl functional groups in Jarosite residue. In UV-visible spectroscopy, the Jarosite residue showed stronger absorption response (~324 nm) with increased electronic activity, while the absorption maximum of Kota stone slurry was found to be lower (~265 nm). The crystallite size and the microstrain investigation showed that the lattice of Jarosite residue is more defected and strained than the fairly well- ordered crystalline material of the Kota stone slurry. Kota stone slurry can be used in bulk engineering applications like construction and fillers whereas Jarosite residue can be used in reactive environmental applications after stabilization. These results suggest that the study offers a structure-based framework for sustainable waste valorization and promotes the development of reuse solutions customized to unique applications.***

Keywords: Fourier Transform Infrared spectroscopy, Jarosite residue, Kota stone slurry, UV–Visible spectroscopy, Waste valorization, X-ray Diffraction.

1. Introduction

The use of industrial mineral resources yields large amounts of solid waste which if not effectively managed can contribute to dust pollution, land degradation, blockage of drainage, changes in the soil characteristics and the creation of hazardous or acid leachates.(Akhtar & Kulhary, 2025)(Gupta & Prasad, 2018). Consequently, a complete physicochemical characterization and a valorisation according to the individual purpose are important for a sustainable management of these residues.

The mineral wastes jarosite residue and kota stone slurry are quite distinct in their composition and environmental behaviour. When cut, polished and shaped, Kota limestone produces Kota stone slurry which is mainly composed of fine carbonate particles with silica bearing phases.(Mombelli et al., 2018) It is rich in calcite and has been reused in concrete, mortar, road sub-base materials, fillers and other construction materials. The disposal of it has caused environmental problems in the area.(Sinha, Havanagi, & Shahu, 2021)

By contrast, jarosite residue is produced when ferric iron precipitates from process solutions during zinc hydrometallurgical processing. Its composition is sulfate-rich iron-bearing, alkali ions and trace metals. It is more chemically reactive and environmentally sensitive than carbonate-based stone debris. However, suitably stabilized or modified jarosite waste can be a precursor for adsorption, metal recovery and production of useful compounds.(Saha & Majumdar, 2026)(Akhtar & Kulhary, 2025; Pappu, Saxena, & Asolekar, 2006)

The different behaviour of these materials is due to changes in mineralogy, bonding environment, crystallinity, surface chemistry and optical characteristics. Information on carbonate, silicate, sulfate, hydroxyl and Fe–O bonding conditions is provided by Fourier transform infrared spectroscopy (FTIR) and crystalline phases such as calcite, quartz and iron sulfate minerals are detected by X-ray diffraction (XRD).The optical and electrical properties were compared using UV-Visible spectroscopy.(A. Singh, Panghal, Siddique, & Chaudhary) However, direct comparative investigations connecting the spectroscopic behavior and mineralogical structure of sulfate rich jarosite waste and calcite rich Kota stone slurry with their probable valorization processes are still scarce.

Therefore, the present work is intended for comparison of features of Kota stone slurry and jarosite residue using XRD, FTIR and UV–visible spectroscopy.(A. S. Shekhawat & Tiwari, 2025b) The study focuses at generating material specific strategies for sustainable exploitation and establishing the link between structure, property and application.

2. Experimental

2.1 Materials

2.1.1 Sample collection

Kota stone slurry was collected from Kota industrial area, IPIA road no 5, Raghoonta udyog, Rajasthan. Samples of typical material were taken from several areas and about 2 kilogram of samples were obtained. The jarosite residue was acquired from industrial waste rich in iron sulfate generated from zinc smelting processes. Jarosite residue is a waste leftover from metallurgical processes. Samples were collected in March-April 2026 from several locations in each of the trash sites.

2.1.2 Sample preparation

The collected Kota stone dust sample was then dried in an oven at 105°C for 24 hr to eliminate the residual moisture. The material was dried and then finely ground and homogenized with an agate mortar and pestle for approximately 2 h for a homogeneous particle size distribution. Similarly the Jarosite residue sample was treated to the same pre-treatment technique of drying overnight in an oven and grinding and homogenization for around 2 hours to achieve homogeneity and consistency in particle size.

2.2 Fourier transform infrared spectroscopy (FTIR)

The functional groups and bonding environments of both samples were characterized by Bruker Alpha II FTIR spectroscopy. The spectra were collected using Standard analytical parameters in the 4000-400 cm-1 region.(Donderiya, Shrivastava, Shukla, & Gupta, 2026)

2.3 X-ray diffraction (XRD) analysis

The crystalline phase composition of the samples was analyzed by XRD (PANalytical, AERIS). The diffraction patterns were recorded in the 2θ region of ~5°-90° with Cu Kα (λ = 1.5406 Å) radiation at 40 kV and 15 mA. (Zhu et al., 2024)

2.4 UV–Visible spectroscopy

The optical properties of the samples were studied by a Shimadzu UV-2600 spectrophotometer in the wavelength range of 200–800 nm.(Das, Kumar, & Naik B, 2025)

3. Results and Discussion

3.1 FTIR Spectroscopic Analysis

The FTIR spectra also further support the separate chemical composition and bonding environment of Jarosite residue and Kota stone slurry (KSS). Characteristic absorption bands of KSS due to asymmetric stretching and bending vibrations of carbonate (CO3 2-) groups are observed at 1416, 870 and 706 cm-1. Other bands observed at ~788 and 1018 cm-1 are associated with Si-O stretching vibrations, suggesting the presence of silicate and quartz phases, respectively. These characteristics are consistent with KSS being largely a carbonate silicate system with minimal hydroxyl or water.But the strong bands at 1004 and 1090 cm^{-1} in the FTIR spectrum of the Jarosite residue are attributed to the stretching vibration of sulfate (SO_4^{2-}). The bands about ~1619 cm-1 and broad absorption around ~3351 cm-1 are attributed to H-O-H bending and O-H stretching respectively, which confirm the presence of Hydroxyl groups and structurally associated water. A low wavenumber band around ~469 cm −1 , attributed to Fe–O lattice vibrations, further supports the iron transporting nature of the material. The characteristic vibrational bands of silicates and carbonates in KSS are shown in Fig. 1.The comparative FTIR study indicated the sulfate hydroxyl chemical environment of Jarosite residue and the dominance of KSS via stable carbonate and silicate bonding. This difference is directly related to their environmental reactivity, the jarosite residue being more susceptible to chemical reactions such as ion exchange and dissolution.

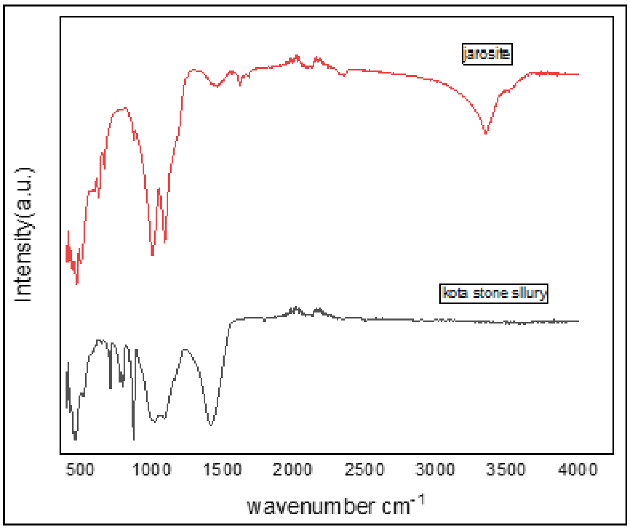


Figure 1: Comparative FTIR spectra of jarosite residue and Kota stone slurry and the characteristic vibrational bands of carbonate, silicate, sulfate, hydroxyl and Fe–O.

Table 1: Comparative FTIR characteristics of Jarosite residue and Kota stone slurry

Parameter	Jarosite	Kota stone slurry
Major absorption bands (cm^{-1})	469, 1004, 1090, 1450, 1619, 3351	460, 706, 788, 870, 1018, 1416
Low-wavenumber region	~469 cm^{-1}	~460 cm^{-1}
Main functional groups	Sulfate, hydroxyl, water-associated groups	Carbonate and silicate groups
Characteristic mid-region bands	1004 and 1090 cm^{-1}	706, 788, 870, and 1018 cm^{-1}
High-wavenumber region	Broad band at ~3351 cm^{-1}	No strong hydroxyl-dominant broad band observed
Probable band assignment	Fe–O/lattice vibration, sulfate stretching, H–O–H bending, O–H stretching	Si–O/lattice bending, carbonate bending, quartz/silica vibration, Si–O stretching, carbonate asymmetric stretching
Dominant chemical character	Sulfate-hydroxyl-bearing iron mineral system	Carbonate-silicate mineral system
Water/hydroxyl contribution	Clearly present	Comparatively less prominent
Mineralogical implication	Hydrated sulfate-bearing phase	Calcite-rich phase with silica contribution
Chemical interpretation	Acidic sulfate residue with structurally bound hydroxyl/waste	Calcareous mineral residue dominated by carbonate groups
Environmental relevance	Can influence acidity and metal mobility	Can contribute to alkalinity and buffering behavior
Application significance	Suitable for reactivity and waste transformation studies	Suitable for neutralization, filler, and valorization applications

3.2 X-ray Diffraction (XRD) Analysis

Advanced Crystallographic Analysis: Crystallite Size, Microstrain and Peak Broadening

Calculation of XRD parameter

The credibility of the crystallographic interpretation is further supported by the constancy of Scherrer findings. The apparent crystallite size for Kota stone slurry was 51.38 nm for the major calcite reflection at 2θ = 29.4999° and 52.50 nm for the quartz-associated reflection at 2θ = 26.7059°(Patidar & Kalla, 2026). These findings are in keeping with the slurry's strong and crisp diffraction peaks, which show a highly crystalline and structurally organized calcite–silica framework(Pandiyan, Solaiyan, & Research, 2024).The considerably finer crystalline domains of the Jarosite residue phase were confirmed by the principal Jarosite residue reflection at 2θ = 29.1699°, which displayed a wider peak profile with an apparent crystallite size of just 31.64 nm(Akhtar & Kulhary, 2025). Further microstrain research showed that the Kota stone slurry had lower lattice strain (ε = 0.00265–0.00286) and Jarosite residue had higher strain (ε = 0.00435 for the primary peak), suggesting that the sulfate-rich iron-bearing residue had higher lattice distortion and defect density(Paridwal et al., 2025). The validation of greater crystalline stability of Kota stone slurry is evident from the smaller peaks. The observed peak widening in Jarosite residue is an indication of decreased crystallite size, increased structural disorder and larger density of reactive sites.(Paridwal et al., 2025). The obtained results strongly support the structure-property relationship seen in the XRD investigation that the Jarosite residue has a more defective and chemically sensitive crystalline framework, whereas the Kota stone slurry acts as a stable and less reactive mineral system.(Patidar & Kalla, 2026).

Crystallinity index (CI) investigations were performed based on interpretation of integrated XRD peak area to find out the structural ordering and crystalline stability of the materials. Crystallinity index is the degree of crystalline order of the mineral structure. The lower this value, the higher the risk of structural disorder and lattice defects. The higher the CI values, the better the crystalline organization and the lower the defect density.

Calculation Formulas

$$CI_{kss} = \frac{Ac}{Ac + A\alpha} \times 100 = 78\ \%$$

$$CI_{Jarosite} = \frac{Ac}{Ac + A\alpha} \times 100 = 52\ \%$$

The somewhat higher crystallinity index of the Kota stone slurry confirms the presence of a well-ordered calcite–silica framework with greater structural stability. The Jarosite residue on the other hand, is significantly less crystalline due to its sulfate carrying phases rich in defects, larger diffraction peaks and higher lattice strain. These findings are in agreement with microstrain and crystallite size data from Scherrer and Williamson-Hall investigations.

Scherrer equation:

$$\frac{K\lambda}{\beta\cos\theta}$$

Microstrain equation:

$$\varepsilon = \frac{\beta}{4\tan\theta}$$

Williamson Hall Analysis:

$$\beta\cos\theta = \frac{K\Lambda}{D} + 4\varepsilon\sin\theta$$

The Williamson-Hall results and the overall diffraction reflections imply a considerably wider structural heterogeneity of jarosite, but the weak linear fit limits the quantitative interpretation.

Where:

- D = crystallite size
- K = shape factor (0.9)
- Λ = X-ray wavelength (1.5406 Å, Cu-Kα)
- β = FWHM in radians
- θ = Bragg angle
- ε = Microstrain

Table 2: Comparative Crystallinity Index Analysis of Kota Stone Slurry and Jarosite

Sample	CI (%)	Structural nature
Kota stone slurry	High crystallinity (~78%)	Highly crystalline and structurally stable
Jarosite	Moderate crystallinity (~52%)	Defect-rich and strain-dominated crystalline phase

Table 3: Calculated XRD parameters

Sample	Peak assignment	2θ (deg)	FWHM (deg)	Crystallite size, D (nm)	Microstrain (ε)
Kota stone slurry	Calcite main peak	29.4999	0.1599	51.38	0.00265
Kota stone slurry	Quartz-associated peak	26.7059	0.1555	52.50	0.00286
Jarosite residue	Main Jarosite residue peak	29.1699	0.2595	31.64	0.00435
Jarosite residue	Low-angle Jarosite residue peak	11.6139	0.1170	68.26	0.00502

The X-ray diffraction (XRD) patterns of Jarosite residue and Kota stone slurry (KSS) provide comprehensive information on their lattice properties, phase composition, and crystallographic structure(Akhtar & Kulhary, 2025). A prominent reflection at 2θ = 29.49°, which corresponds to the (104) plane of calcite ($CaCO_3$), dominates the XRD pattern of KSS, indicating a highly crystalline carbonate framework. A composite calcite–quartz mineral system is indicated by additional reflections at 2θ = 26.71°, 36.07°, 39.53°, 43.27°, 47.61°, and 48.62° that are assigned to quartz (SiO_2) and related silicate phases(S. Singh, Choudhary, Kumar, & Gupta, 2020). These peaks' sharpness and intensity point to a crystal structure that is well-ordered and has few lattice imperfections.On the other hand, a sulfate-rich iron-bearing crystalline phase is confirmed by the XRD pattern of jarosite, which displays distinctive reflections at 2θ ≈ 11.60°, 14.93°, 17.54°, 20.70°, 28.63°, and 29.16°(Patidar & Kalla, 2026). The comparatively wider peaks, which represent structural disorder and a greater defect density, show lower crystallite size and increased lattice strain.The Scherrer equation was used to determine the crystallite size of each sample(Donderiya, Shrivastava, Shukla, & Gupta, 2025). Jarosite residue showed a smaller crystallite size of around 31.64 nm, whereas Kota stone slurry showed crystallite sizes of about 51–53 nm. Jarosite residue (ε = 0.00435) has a more deformed and defect-rich crystal structure than KSS (ε ≈ 0.00265–0.00286), according to microstrain research. Williamson-Hall analysis was used to further differentiate between peak broadening caused by strain and size(Sinha et al., 2021). A stable and homogeneous crystalline structure was confirmed by the KSS sample's excellent linear fit (R^2 = 0.927), which produced an average crystallite size of around 107 nm and low microstrain (ε ≈ 0.00139). Conversely, Jarosite residue exhibited a lower regression coefficient (R^2 = 0.515) and a larger microstrain (ε ≈ 0.00263), indicating that phase heterogeneity, lattice distortion, and structural complexity are the causes of peak widening (1. Zhu, 2024).In general, the XRD investigation shows that Jarosite residue has a strain-dominated, defect-rich sulfate lattice, whereas Kota stone slurry is a highly crystalline and structurally stable carbonate–silica compound. Their reactivity and potential for use are directly impacted by these variations(Patidar & Kalla, 2026).

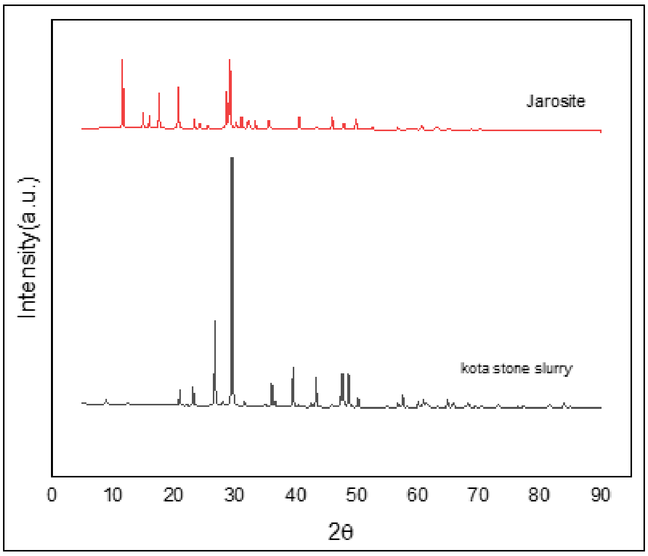


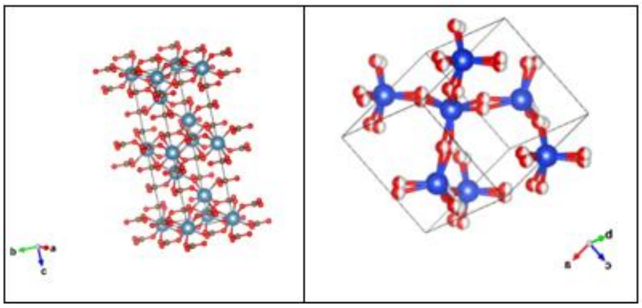
Figure 2: XRD patterns of Kota stone slurry and jarosite residue showing calcite-quartz and sulfate-rich iron bearing phases respectively

Table 4: Comparative XRD characteristics of Jarosite residue and Kota stone slurry

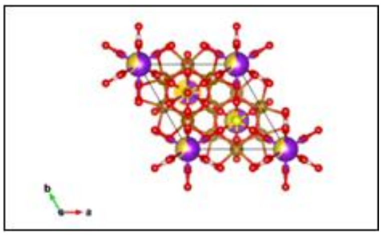
Parameter	Jarosite	Kota stone slurry
Material type	Industrial waste residue	Industrial waste residue
Dominant mineralogical character	Sulfate-rich iron-bearing phase	Calcium carbonate-based calcareous phase
Most intense peak (2θ)	11.60	29.49
Dominant d-spacing (Å)	7.620	3.027
Peak distribution	Broadly distributed reflections over the scanned range	Sharp and intense reflections dominated by carbonate peaks
Probable dominant phase	Jarosite-type iron sulfate phase	Calcite-dominated phase
Associated phases	Sulfate-bearing iron mineral components	Calcite with silica/silicate-associated phases
Structural interpretation	Complex crystalline sulfate framework	Well-crystallized carbonate matrix
Environmental implication	Greater possibility of acidic and metal-related reactivity	Greater buffering and neutralization potential
Application significance	Relevant for waste transformation and reuse studies	Relevant for filler, neutralizing, and sustainable reuse applications

3.3 Structure Property Relationship and Comparative Evaluation

Strong structure-property relationships for both materials are established by a thorough evaluation of XRD, FTIR, and UV-visible data. Because of its high crystallinity and robust carbonate bonding, KSS's calcite–quartz framework produces low reactivity, excellent mechanical stability, and appropriateness for bulk applications such fillers, building materials, and soil stabilization.The natro jarosite, on the other hand, has a sulfate-rich, iron-bearing structure with a higher defect density and notable optical activity(Akhtar & Kulhary, 2025). After proper stabilization, the presence of hydroxyl groups, water molecules, and iron centers increases its chemical reactivity and surface activity,may be considered for adsorption, catalysis and wastewater treatment after appropriate stabilization and further validation.(A. S. Shekhawat & Tiwari, 2025b). The present XRD dataset does not verify its existence conclusively.The spectroscopic behaviour and mineralogical composition are important factors in determining the use fulness of material.(Pappu et al., 2006).Jarosite residue is more appropriate for reactive and functional environmental applications, whereas KSS is more appropriate for passive and structural applications. Fig. 3 presents the crystal morphologies of the mineral phases present in the Jarosite residue and Kota stone slurry.



(a) Calcite (b) Quartz



(c) Natrojarosite

Figure 3: Comparative crystal structures of mineral phases identified in Kota stone slurry (a, b) and Jarosite residue(c) based on XRD phase analysis

3.4 UV–Visible Spectroscopic Analysis and Comparative Optical Evaluation

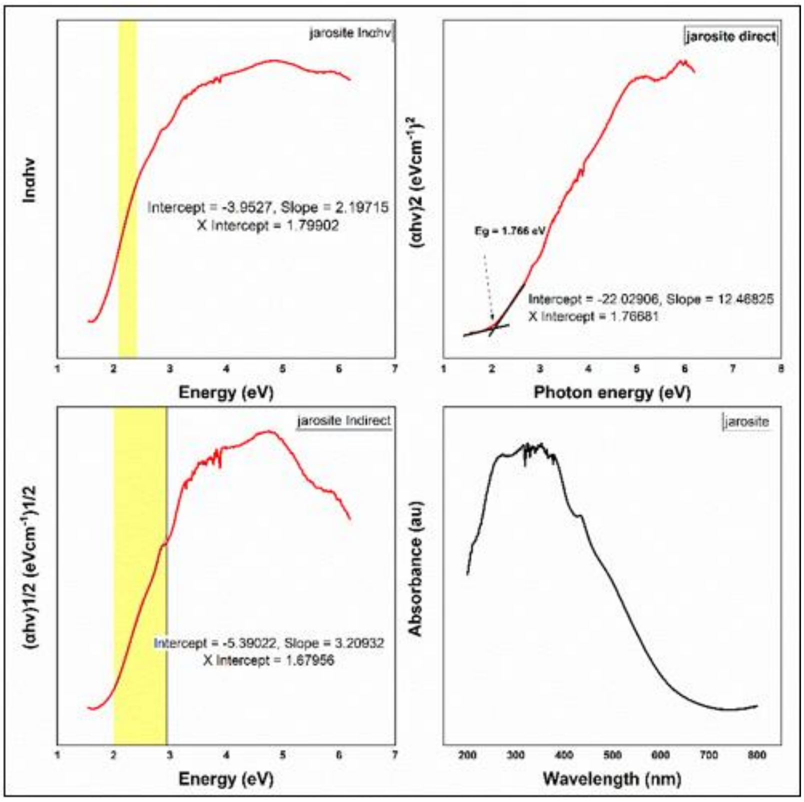
The optical and electrical properties of the two materials vary significantly, as seen by the UV-visible absorption spectra(Gupta & Prasad, 2018). With a low total absorbance and a comparatively weak absorption maximum at around 265 nm, KSS shows few electronic transitions within its carbonate-dominated structure in Table.3(Jangid, Grover, Khatti, Meena, & Koli, 2025). demonstrates that modest defect-induced states and low optical activity are suggested by the lack of substantial absorption in the visible range. Jarosite, on the other hand, has a wide, strong absorption peak at around 324 nm with a much greater absorbance intensity, suggesting accelerated electronic transitions linked to iron (Fe^{3+}) centers(Ramamoorthi, Meena, & Sciences, 2018). The existence of defect states and intricate electrical interactions inside the sulfate lattice is suggested by additional absorption characteristics that extend into the visible range. Jarosite residue has a direct band gap of around ~1.76 eV and an indirect band gap of about ~1.9–2.0 eV, according to band gap estimates using Tauc plot analysis, whereas KSS shows a similar but slightly broader band gap (~1.7–2.1 eV). Jarosite residue has more optical activity while having identical band gap ranges because of its iron-rich composition, which promotes electronic transitions(Fortier et al., 2021).These findings show that although KSS is still optically less active and chemically stable, Jarosite residue has better light absorption and electrical responsiveness, making it appropriate for uses like photocatalysis and environmental cleanup applications(Ali et al., 2023)The existence of localized states inside the band gap is suggested by the observed absorption tail.By extending the linear area of the absorption edge, the Tauc relation was used to determine the optical band gap values. Jarosite's greater absorption response and somewhat smaller band gap suggest accelerated electronic transitions linked to lattice defects and Fe^{3+}-related states.(Boostani, Najafi-Ghiri, & Khalili, 2025).

Table 5: Comparative UV–Visible spectral characteristics of Jarosite residue and Kota stone slurry

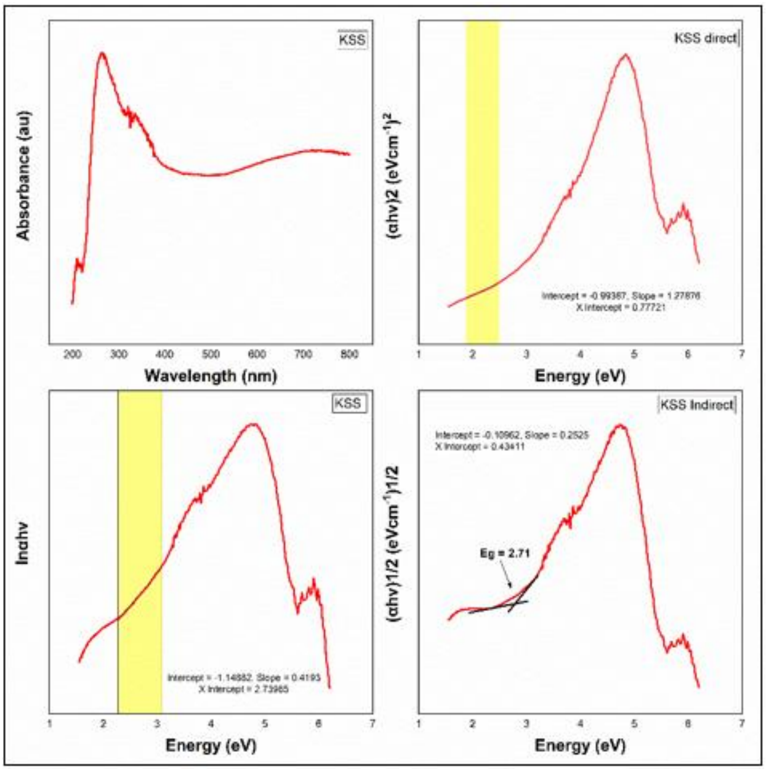
Parameter	Jarosite residue	Kota stone slurry
Spectral range studied	200–800 nm	200–800 nm
Maximum absorbance, Amax	1.260	0.271
Wavelength at maximum absorbance (λ max)	324 nm	265 nm
Other notable absorption features	273, 353, 375, 433 nm	285, 321, 342, 364 nm
General absorbance level	High	Low to moderate
Optical behavior	Strong and broad absorption response	Comparatively weak absorption response
Probable reason	Iron-bearing sulfate phase and stronger electronic transitions	Calcium carbonate-based matrix with relatively low optical activity

Comparative interpretation	More optically active and structurally responsive material	Less optically active material with simpler spectral behavior
Possible implication	Better light interaction and higher surface/electronic reactivity	Lower electronic transition intensity and milder optical response
Stability	Moderate to low stability; prone to structural alteration under acidic or aqueous conditions due to sulfate-rich composition	High structural and chemical stability owing to well-crystallized carbonate lattice and inert silicate phases
Environmental Risk	Potentially high environmental risk; may contribute to acidity generation and heavy metal leaching if not properly stabilized	Low environmental risk; acts as buffering material and can neutralize acidic environments due to alkaline carbonate content
Industrial Application	Suitable for advanced applications such as may have potential for adsorption, catalysis, may be considered wastewater treatment, and may have potential for energy-related materials after stabilization or modification	Suitable for bulk applications such as construction materials, cement replacement, fillers, road sub-base, and soil stabilization

Both samples' UV–visible absorption spectra show substantial absorption in the ultraviolet area with a progressive tail extending into the visible range, suggesting the existence of sub-band gap transitions and defect-induced electronic states (Ali et al., 2023). While Kota stone slurry (KSS) has a somewhat lesser absorption peak at around 265 nm, Jarosite residue displays a noticeably greater absorbance intensity with a pronounced absorption maximum at approximately 324 nm(Kumar & Golani, 2023). Jarosite's longer visible tail and greater absorbance indicate accelerated electronic transitions, which may be explained by defect states in the sulfate-rich lattice and Fe^{3+}-related charge transfer processes(Ryu & Kim, 2022). Jarosite residue has a direct band gap of around 1.76 eV and an indirect band gap between 1.9 and 2.0 eV, according to Tauc plot analysis (Fig. 4). KSS, on the other hand, has a somewhat greater indirect band gap (~2.0–2.1 eV) and a comparable direct band gap (~1.7–1.8 eV), suggesting a comparatively less active electrical structure. Because of its greater absorbance intensity and stronger light-matter interaction, Jarosite residue exhibits a more noticeable in general optical response while having similar band gap values (1). Jarosite's iron-bearing structure, which promotes d–d transitions and charge transfer processes and raises its electrical responsiveness, is directly linked to its increased optical activity. On the other hand, KSS's carbonate–silica matrix produces less optical activity and weaker electronic transitions. These results imply that KSS is better suited for applications where structural stability is more important than optical performance, whereas Jarosite residue is more appropriate for applications requiring substantial light absorption and electronic activity(Elwood Madden, Bodnar, & Rimstidt, 2004). such as photocatalysis and environmental cleanup. The optical parameters are further summarized in Table 6.



(a)



(b)

Figure 4: UV–Visible absorption spectra and corresponding Tauc plots of (a) Jarosite residue and (b) Kota stone slurry (KSS), showing differences in absorption intensity, visible-light response and estimated direct and indirect band gap energies

Table 6: Comparative Optical Parameters Derived from UV–Visible Analysis

Sample	Absorption Range(nm)	Absorption Nature	Direct band gap (eV)	Indirect band gap (eV)	Key Observations
Jarosite residue	200–400 (strong UV), tail up to ~700	Strong UV absorption with visible tail	~1.76 eV	~1.9–2.0 eV	Narrow band gap, good visible light response, presence of defect states indicated by tail
Kota stone slurry	250–350 peak, gradual decrease till ~800	Intense UV peak with extended visible absorption	~1.7–1.8 eV	~2.0–2.1 eV	Slightly broader absorption, possible structural disorder and intermediate energy states
Comparative Insight	UV+ Visible region	Mixed transition behavior	Comparable	Slight variation	Coexistence of direct & indirect transitions enhances photocatalytic potential

3.5 Environmental and sustainable application perspective

From an application perspective, KSS is a promising material for sustainable building materials, such as filler, road sub-base, and cement replacement, due to its calcium carbonate-based nature and structural stability(Miller, 2014). Additionally, its natural alkalinity aids in soil stability and environmental buffering. Whereas, jarosite residue reactive properties, which are fueled by its sulfate and iron concentration (1). provide a great deal of promise for environmental remediation techniques such heavy metal adsorption, pollutant catalytic degradation, and energy-related uses(R. S. Shekhawat, Kushwaha, & Agarwal, 2026). Whereas, before using it, it must be properly stabilized or modified owing to possible environmental hazards, such as acidity and metal leaching(Navrotsky, 2002).

3.6 Mechanism of Waste Valorization

The comparative mineralogical investigation concludes that the calcium carbonate-based structure of Kota stone slurry provides structural stability and alkaline buffering which is useful for cementitious and construction purposes. Calcite and silica phases can be added to the mortar and concrete to improve the particle packing, porosity and compressive strength..(Bishop, 2005). Jarosite residue is characterized by sulfate-rich iron-bearing phases with enhanced electrical and surface activity. After stabilization or thermal change, such features can enhance the adsorption, catalytic interaction and immobilization of pollutants. So sustainable material engineering is applying leftovers in diverse structural ways.(Benavente, Pla, Valdes-Abellan, & Cremades-Alted, 2020).

3.7 Environmental Risk and Stability Assessment

The environmental stability is important for the reuse of industrial waste. The sulfate-rich composition of jarosite residue residue may induce acidity and trace metal mobility in unfavorable conditions.(Zhu et al., 2024). It needs to be stabilized and encapsulated before wide scale application. On the other hand, the Kota stone slurry inert carbonate mineralogy, stronger buffering capacity and less environmental reactivity have been discussed. Its alkaline nature may benefit the environmental threat is neutralized and mitigated in the case of bulk reuse.(Ge et al., 2023).

3.8 Future Scope

The Jarosite residue and the slurry of Kota stone are proposed to study the thermal activation, chemical stabilization and composite fabrication. More sophisticated techniques like SEM-EDS, XPS, BET surface area analysis, and leaching may better elucidate structure-property-performance relationships. Its use at pilot scale for environmental clean-up and construction systems should be researched for industrial application.

4. Conclusion

The scientific technique of structure-driven waste valorization presented in the present work enables the development of sustainable and application-specific reuse options for industrial materials. In this paper a comprehensive comparative study of Jarosite residue and Kota stone slurry is presented by analyzing the XRD, FTIR and UV-visible spectroscopy to determine structure-property relations for sustainable applications. The experimental data reveal that the Kota stone slurry has a stable calcite-quartz mineral framework with little optical activity, while the Jarosite residue has an iron sulfate mineral framework with significantly enhanced electrical reactivity. These distinctions have direct implications on their potential applications where the Kota stone slurry may be suitable for bulk reuse in construction related applications and the Jarosite residue has potential for reactive environmental applications with adequate stabilization. The study points out that a structure-driven approach where spectroscopic behavior and mineralogical composition lead to material specific application strategies is needed for successful waste valorization. The results obtained suggest that both materials can be reused in different ways, depending on their mineral content and reactivity. for the characterization of industrial wastes in terms of their fundamental properties, therefore enabling the formulation of sustainable and application-oriented waste management strategies. The current study promotes circular-economy concepts of the circular economy by converting industrial waste leftovers into useful secondary resources.

5. Limitation

The present work is limited to structural and spectroscopic characterisation. Further investigations on adsorption, leaching, photocatalysis and mechanical performance are needed to validate large scale industrial applications.

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Conflicts Of Interest
There is no conflict of interest to declare

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