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Chemical Synthesis And Characterization Of Lanthanum Oxide Nanoparticle Extended By Machine Learning Prediction

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Abstract: *Low-cost co-precipitation method has used to synthesis the La_2O_3 nanoparticles at room temperature. The regression-based prediction model for estimating the optimal crystal size and respective strain has also presented. Energy Dispersive X-ray Spectroscopy (EDS), Scanning Electron Microscopy (SEM), Fourier Transform Infrared (FTIR) spectroscopy, and X-ray diffraction (XRD) were used to characterize the nanoparticles. With a particle size of 7.13nm and 7.92nm, a hexagonal structure has been formed, confirmed by XRD analysis. FTIR spectroscopy verified the existence of La-O stretching modes. The SEM images revealed the annealing effect on grain size and their agglomeration. The elemental composition of nanoparticles was determined by EDS analysis. The resulting nanoparticles morphology and properties were significantly influenced by the annealing temperature. Proposed method offers R^2 value of 0.9836 justifying the effectiveness of prediction.*
Key Words: *Nano particles, co-precipitation method, Machine Learning*

1. INTRODUCTION

Particles with a size between 1 and 100 nm are called nanoparticles (NPs). Because of their exceptional physical and chemical characteristics, which set them apart from bulk materials, nanomaterials are becoming increasingly important in a wide range of applications [1].Lanthanum oxide (La_2O_3) based nanoparticles are getting substantial attention in materials research due to their distinctive characteristics and prospective uses in numerous industries N.Ramjeyanthi et al [1] in 2018.In the case of low-temperature usage, especially magnetic refrigeration, the magnetocaloric effect is an important factor to take into account. For materials like Tb_2O_3 and Dy_2O_3 nanoparticles, this effect, this depends on entropy changes brought on by magnetic fields. It is noticeable in cryogenic temperature ranges [2]. Because they use less energy and have a smaller environmental impact than traditional cooling systems, these effects are being thoroughly studied as alternatives. Undoped lanthanum oxide La_2O_3 nanoparticles offer advantages over Tb_2O_3 and Dy_2O_3, including low toxicity to aquatic organisms and improved structural and optical properties. However, there isn't much specific studies reported on un-doped La_2O_3 nanoparticles. In recent times research is motivated towards utilizing the synthesis results to design machine learning (ML) based prediction to investigate the optimal crystal size and strain. Since broader peak in XRD can also indicate increased strain or defects within the crystal structure. This can affect the mechanical strength and stability of the nanoparticles. Thus, it is required to accurately predict the optimal synthesis parameters and is the one scope of this study.

The La_2O_3 nanoparticles have garnered significant attention in materials science due to their unique properties and potential applications. The preparation temperature profile has an impact on the synthesis of La_2O_3nano particles as reported by S. Karthikeyan et al [3]. While moderate-temperature profiles produce well-defined NPs with enhanced crystallinity, low-temperature profiles lead to incomplete production. Larger, more crystallinity-producing NPs are encouraged by high-temperature profiles; yet, agglomeration and morphological loss may result at high temperatures. Extremely high temperature profiles have the potential to induce notable morphological and growth alterations. Because of its special qualities and prospective uses in a variety of industries, La_2O_3 nanoparticles have attracted a lot of interest in materials research. Therefore, this research paper aims to cover the synthesis for La_2O_3 nanoparticles using a simple and cost-effective co-precipitation method. By exploring different annealing temperature (160°C, 190°C), this work offers valuable insights into the impact of temperature on nanoparticle morphology, crystallinity, and properties.

2. CHALLENGE OF SYNTHESIS OF NANO PARTICLES

There are many challenges to be addressed for the successful synthesis of Lanthanum Oxide Nanoparticles. The multifaceted nature of synthesizing La_2O_3 nanoparticles is not merely a chemical reaction but a complex process requiring careful management of environmental factors, temperatures, and the inherent properties of the material to achieve the desired outcome. Most essential challenges are as follows and are illustrated in the Figure 1.

- **High Reaction with Moisture and CO_2:** Lanthanum oxide is highly reactive with atmospheric moisture and carbon dioxide, requiring strict control of the synthesis environment.
- **Need for High Temperatures:** High temperatures are required for the synthesis of La_2O_3 nanoparticles, posing energy consumption and equipment limitations.
- **Reliability and Scalability Challenge**: Consistency in production and the ability to increase yield while maintaining quality are crucial for commercial applications.

Fig. 1 challenges in the synthesis of nanoparticles of lanthanum oxide

- **Security and Management:** Proper safety protocols and material management are essential when working with these compounds.
- **Nanoparticle Agglomeration Challenge:** Preventing or reducing agglomeration is crucial for achieving desired performance characteristics.
- **Control of Particle Dimensions and Morphological Challenge:** Providing precise control over the size, shape, and overall morphology of the nanoparticles is a critical challenge.

The creation of nanoparticles has historically been dominated by chemical and physical techniques. However, they frequently have drawbacks including the requirement for strong reaction conditions and environmental problems. Green synthesis techniques, which create nanoparticles using biological entities like bacteria and plants, are therefore gaining popularity. Although these green techniques are thought to be more sustainable and ecologically benign, they do have drawbacks, such as the need to scale up for big production and maintain stability through synthesis [7,8].Therefore, this paper is aimed to successfully synthesize the nano particles by chemical route and annealed at different temperatures.

3.REVIEW OF SYNTHESIS OF NANO PARTICLES

Shinde et al. [2] investigated the magnetocaloric effects in La_2O_3 materials. While P Ram Kumar et al. [4] looked into the hydroxyl radical scavenger action of La_2O_3 nanoparticles, highlighting their biological significance; S. Karthikeyan et al. [3] explored the effects of elevated temperatures on La_2O_3 nanostructures.S. Rahul obtained an interesting result suggesting the apparent increase in crystalline nature as the synthesis time was extended confirmed by XRD[5] . Ismail etal [6] have synthesized lanthanum oxide La2O3 nanoparticles NPs by laser ablation in water without using surfactant, they were tried to find the effect of laser wavelength on the optical and structural properties of La2O3 NPs. The study of mycogenic nanoparticles, their fungal manufacture, and

their uses in environmental cleanup and medicine, Khandel and Shahi [7] highlight the difficulties and current state of using these biogenic materials.

Numerous green synthesis techniques, such those used by Joshi et al. [9], with leaf extract from Syzygium cumini and with Cannabis sativa [8], show the tendency toward ecologically benign ways to produce nanoparticles. New methods for La_2O_3 nanoparticles targeted for CMOS applications that use propylene glycol and glutaric acid Pathan et al. [10]. By rigorously analysing the Scherrer and Debye-Scherrer equations, Holzwarth and Gibson [11] advanced our knowledge of how to determine the size of nanoparticles using X-ray diffraction techniques. The basic work in crystallite size analysis by Williamson and Hall [12] is still relevant in today's research. Anu Krishna and Tharayil [13] highlighted the suitability of La_2O_3 nanoparticles for electrical applications by concentrating on their dielectric characteristics after synthesizing them using chemical co-precipitation. Examining the synthesis and optical characteristics of different lanthanum hydroxide as well as oxide NP's, Mu and Wang's work [14] focused on shape-preserved changes, which are essential for customizing material properties. Furthermore, La_2O_3 nanoparticles' capacity to scavenge hydroxyl radicals was examined by P Ram Kumar et al. [15], suggesting that they may find use in biomedical applications. Collectively, these investigations highlight the adaptability and importance of lanthanum oxide nanoparticles in a variety of scientific domains.

Jayadeep Tejani et al. [16] presented a controlled synthesis of lanthanum nanorods [16] serves as another example of how nanoparticle morphology may now be tailored for certain uses. Glutaric acid as well as propylene glycol were used in a synthesis method created by Pathan et al. [17] to improve the material's characteristics for CMOS applications. Furthermore, new synthesis pathways utilizing glutaric acid and combustion techniques, respectively, were introduced by investigations such as those of Khalaf & Al-Mashhadani [18].Applications in cutting-edge technology and production techniques have been the main topics of recent studies on lanthanum oxide La_2O_3 nanoparticles. Metal-oxide nanomaterials, such as those based on lanthanum, were investigated by Yeosang Yoon et al. [19] in flexible sensors for environmental and health monitoring. In their study of the controlled production of lanthanum nanoparticles, Tejani et al. [20] shed light on their structural characteristics and potential uses in catalysis and electronics.

Current reviews, such as Bhautik's [21], highlight the continuous research in this field by summarizing several synthesis and characterisation methods for La_2O_3. The biological uses and photocatalytic capabilities of La_2O_3 nanoparticles are further investigated in studies by Hanif et al. [22] as well as Pranali S. Parab et al. [23]. Novel manufacturing techniques and catalytic uses have been brought to light by recent research on lanthanum oxide nanoparticles.A unique method for creating La_2O_3 nanoparticles using nano-sized lanthanum (III) molecules was presented by Parimala Gandhi et al. [24]. Tao et al. [25] examined methods for data-driven synthesis optimization and investigated the incorporation of ML methods in nanoparticle synthesis. In order to show the potential of La2O3 in catalytic applications and environmental remediation, Velinova et al. [26] studied the synthesis and characterisation of Pd/La2O3/ZnO catalysts for the oxidation for methane, propane, along with butane. Together, these pieces demonstrate the various techniques and uses of La_2O_3nanoparticles, opening the door to novel applications in environmental remediation, catalysis, and nanomedicine. The Table 1 have presented the summary of the various Nanao particle synthesis literature summary.

Table. 1 Survey for Nanoparticle synthesis and methods

Reference	Methodology	Nanoparticle	Synthesis Method
N. Ramjeyanthi et al [1]	Co-precipitation	La2O3	Co-precipitation method
Shinde et al [2]	Magnetocaloric effect	Tb2O3, Dy2O3	Rare earth nitride formation and successive oxidation
S. Karthikeyan et al [3]	Temperature effects	La2O3 nanostructures	Simple Reflux Method
P Ram Kumar et al [4]	Hydroxyl radical scavenging	La2O3	Co-precipitation and Field emission scanning electron microscopy (FESEM)
Khandel & Shahi [7]	Mycogenic applications	Mycogenic nanoparticles	Mycogenesis of nanoparticles
Ahmadi & Lackner [8]	Green synthesis	Silver	Green synthesis from Cannabis sativa
Joshi et al [9]	Green synthesis	α-Fe2O3	Leaf extract of Syzygiumcumini

Pathan et al [10]	Glutaric acid & propylene glycol	La2O3	Chemical synthesis
P. G. Anu Krishna et al [13]	Dielectric properties	La2O3	Co-precipitation method
Qiuying Mu &Yude Wang [14]	Shape-preserved transformation	La(OH)3, La2O2CO3, La2O3	A chemical synthesis (or facile process)
Jayadeep Tejani et al [16]	Controlled synthesis	Lanthanum NR's	Controlled synthesis
Khalaf & Al-Mashhadani [18]	New combustion method	La2O3 net-like	Combustion method
Hanif et al [22]	Citrus aurantium extract	La2O3	Chemical synthesis
Pranali S. Parab et al [23]	Doping and coating	La2O3	Green synthesis approach
K. Parimala Gandhi et al [24]	Novel synthesis	La2O3	Sono-chemical method and (FESEM)
Tao et al [25]	Machine learning-assisted	Various nanoparticles	Co-precipitation and Machine learning techniques
Velinova et al [26]	Catalyst development	Pd/La2O3/ZnO	catalytic oxidation with palladium deposition

Table 1 summarizes various methodologies employed in the synthesis of nanoparticles, highlighting a range of materials and techniques used by different researchers with co precipitation method highly referred.

4. SYNTHESIS PROCESS AND STEPS

The sequential steps involved in the synthesis of La_2O_3 nanoparticles using the chemical Co precipitation method, are as described below,

- The powder of Lanthanum Nitrate Hexa Hydrate ($La(NO_3)_3 \cdot 6H_2O$) &Sodium Hydroxide (NaOH) are the basic precursors used for the synthesis of the sample. Initially solution of 0.1M for lanthanum nitrate and of 0.3M for NaOH was prepared by mixing each in 100mL of distilled water in two separate beakers.
- The prepared solution of NaOH was drop wise added to the precursor solution of lanthanum nitrate kept on magnetic stirrer.
- The solution was agitated at normal temperature for 140 minutes with constant speed. At the beginning of the reaction the pH was found to be 12 and finally reaches up to 14 at the last.
- Now the solution was kept at rest for 8h, by which the precipitate was settled down at the bottom.
- Now remove the excess water from beaker and further cleaned multiple times with distilled water and once with ethanol.
- This cleaning process is followed by filtration and congregated in watch glassand then air dried till 96 hours at normal room temperature.
- Again, the sample was kept in electric oven at the temperature of 160 ℃ and190℃ for one hour separately. Lastly, the dried precipitate was crush into fine particles using mortar and pestle.

5. RESULTS

The XRD measurements are used to understand the qualitative analysis of sample. The X-ray diffraction pattern of Lanthanum oxide synthesised by co-precipitation method and annealed at 160°C and 190°C are shown in figure 2.One can conclude from the appearance of more than one prominent peak that the prepared lanthanum oxide samples are polycrystalline in nature. The main peaks observed at 2θ (deg.) 15.74°, 26.3°, 28.08°, 31.67° and 39.4°are in good agreement with JCPDS card no. 83-2034 (COD:4031381) corresponds to the hexagonal phase of $La(OH)_3$. Along with this extra peak around 30.1°, 40.0° and 48.7° is also observed, corresponds to pure La_2O_3(JCPDS-05-0602) with hexagonal phase. At lower annealing temperature some traces of $La(OH)NO_3$ (COD:4344281) is also observed. The structural characterization of the synthesized nanoparticles was performed using X-ray diffraction (XRD) analysis [11, 12]. The fundamental XRD characterization is defined as;

$$n\lambda = 2dsin(\theta) \quad (1)$$

Where, n stands for reflection order, λ is X-ray wavelength (λ=1.5418A^0)), d is defined as interplanar spacing, and finally the θ is diffraction angle(or Bragg angle)at peaks. By utilizing the Debye-Scherrer equation (2) [11], the mean crystallite size (D in nm) for the La_2O_3 nanoparticles was determined as,

$$D = \frac{K.\lambda}{\beta\cos(\theta)} \quad (2)$$

where K is set to as constant value of (0.94), and β is defined as full width of the half maxima(FWHM) Holzwarth et al. [11] and Williamson-Hall [12]. The mechanical strain is mathematically defined as;

$$\varepsilon = \beta/4tan\theta \quad (3)$$

The values so obtained for grain size, inter-planner spacing, FWHM, Mechanical strain are presented in table2 given below. It is observed that on increasing the annealing temperature the particle size and mechanical strain increases.

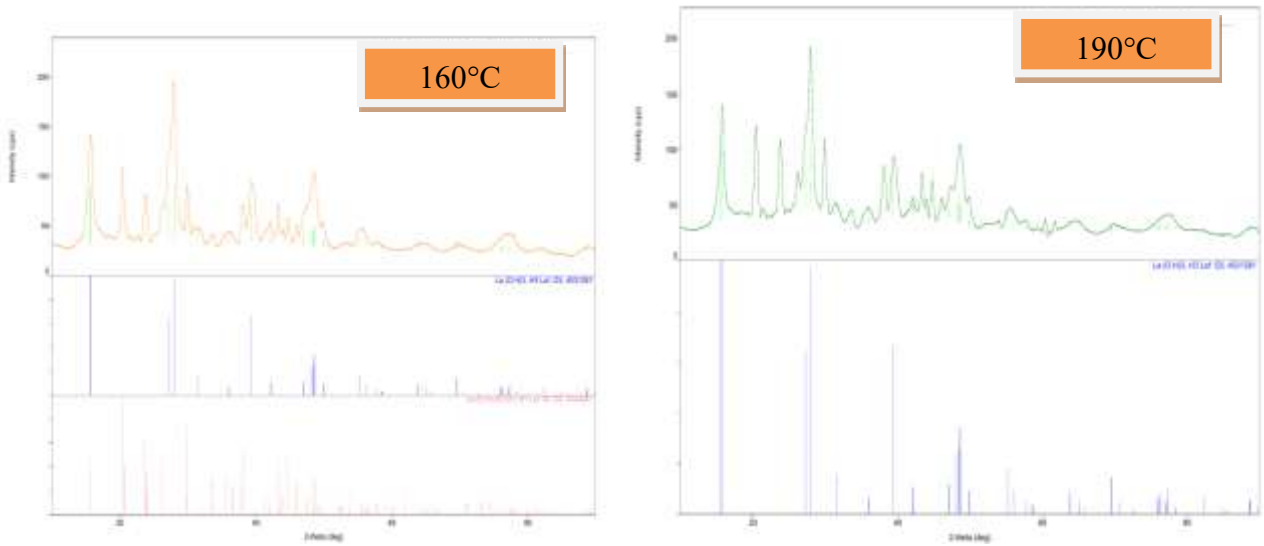

Figure2 XRD characterization results for samples annealed at 160 °C and 190°C.

Compound	Temp.	JCPDS- 83-2034 (COD-4031381)	Obtained values for lattice para	Interplaner spacing d (A°)	FWHM	Grain size (nm)	Mechanical Strainε
$La(OH)_3$	160°C	a=b=6.547 c=3.85	a=b=6.466, c=3.84	3.17	1.20	7.13	0.02924
$La(OH)_3$	190°C	a=b=6.547 c=3.85	a=b=6.235, c=3.97	3.23	1.08	7.92	0.051133

Table 2: Key parameters obtained by XRD analysis

When describing the creation of nanoparticles Fourier Transform Infrared (FTIR) spectroscopy is a useful tool to identify the presence of chemical bonding and functional group in the material. Certain vibrational modes experienced by the molecules in the sample are represented by the peaks and troughs within the spectrum at different wave numbers; the spectrum displays a number of notable peaks

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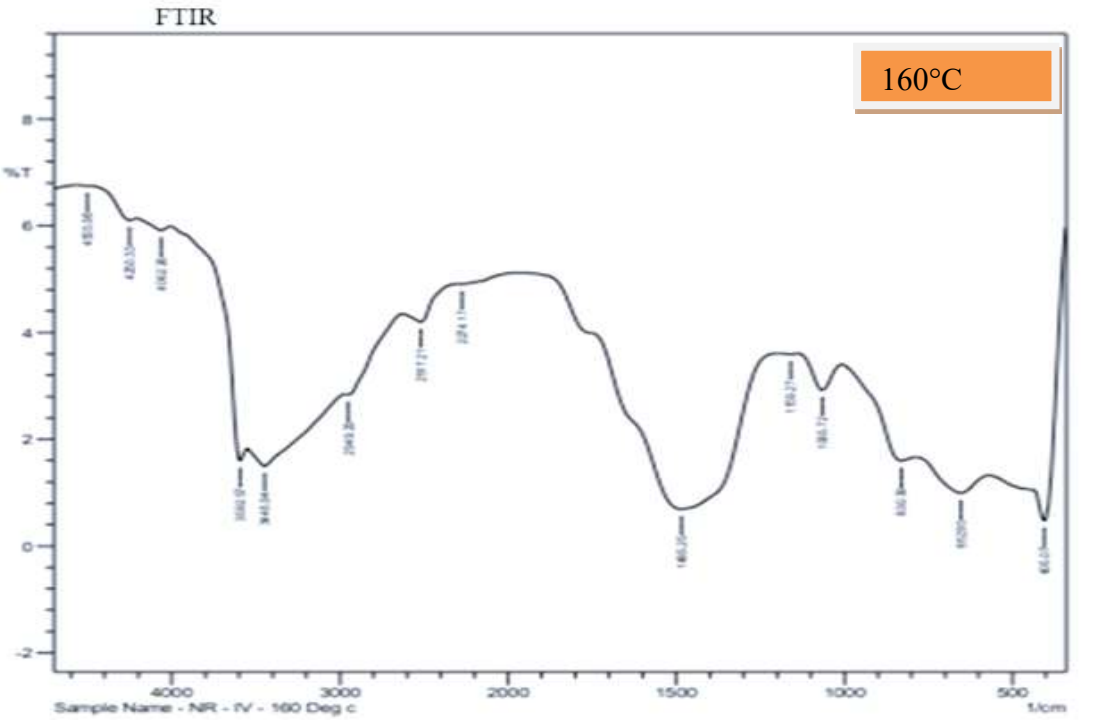

Figure 3 Results of the FTIR spectral peak analysis validated at 160 °C

The distinctive absorption bands for La-O stretching vibrations and peaks for hydroxyl groups as well as carbonate species that can appear during synthesis are usually visible in FTIR spectra of lanthanum oxide nanoparticles.

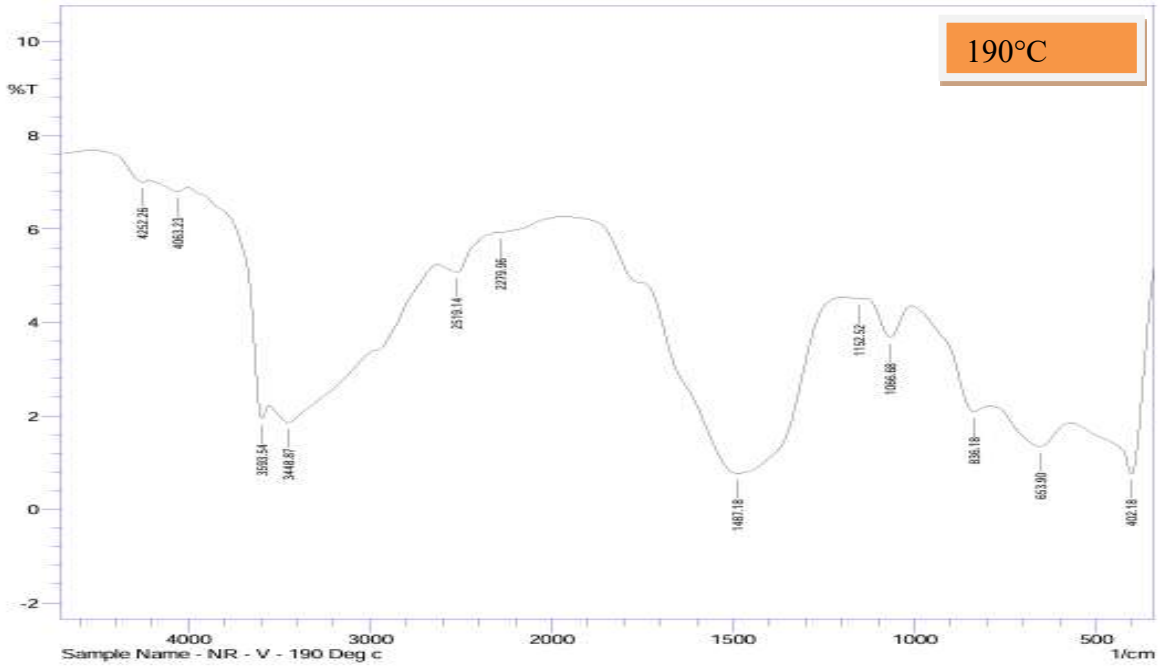

Figure 4 Results of the FTIR spectral peak analysis validated at 190 °C

Wave number (cm^{-1}) $160^{O}C190^{O}C$	Functional Group/Band Assignment	References

2517.21 2949.29 3446.94 3592.57 4062.26	2519.14 3448.87 3593.54 4063.23 4252.26	Single bond, hydrogen bond due to presence of H_2O	[1]
2274.17	2279.96	Triple bond, C_N	[2]
1485.25	1487.18	C-C stretching, or CH3 antisymmetric stretching	[2],[4]
1065.72 1159.27	1066.68 1152.52	C-OH, C-O stretching	[2],[4]
830.39	836.18	C-O banding	[3],[4]
652.93 405.07	653.9 402.18	La-O Stretching and bending	[1],[3]

Table 3 Description of Wave Number vs Functional Groups material at 160°C and 190°C

The FTIR spectra in the wavenumber range 4000-400 cm^{-1} of the as-prepared samples are shown in Fig.3,4. At the spectrums of the annealed samples at 160°C in Fig. 3, a broad band is observed at the wavenumber of 4062.26, 3592.57, 3446.94, 2949.29, 2517.21 cm^{-1}respectively and these bands show the presence of O-H stretching vibration which may due to the presence of absorbed moisture on the surface of the samples [1]. The peak around 2274cm-1 may due C-N triple bond [2]. The absorption peaks at around 1485, 1487 cm-1 in the samples is found because of the asymmetric and symmetric stretching of CH3and C-C bond respectively [2,4]. The band observed at 1159, 1152, 1065 and 1066 are due to C-OH, C-Ostretching vibration but in the same samples, the sharp absorption bands at around 830, 836 cm-1 is owing to C-O bending vibration. The broad absorption bands at 652,653 cm-1(F) in samples is observed because of the La-O stretching vibration while the small bands at 405 and 402 cm-1 in the same samples is due to La–O bending vibration. The presence of above mentioned bands therefore confirmed the existence of La_2O_3 [1,3]. The location of all the band frequencies and their corresponding modes of vibration are recorded in Table 3 for better comparison.

Figure 5 presents scanning electron microscopy (SEM) images comparing the morphology of Lathanum hydroxide synthesized at 160°C and at 190°C. Both SEM results show agglomerated nanoparticles. The sample annealed at 160°C appears to have slightly larger and less densely packed agglomerates compared to the 190°C sample, which exhibits smaller, more closely aggregated nanoparticles. The scale bar indicates a 1 µm scale for both images, allowing for a direct visual comparison of particle size and distribution.

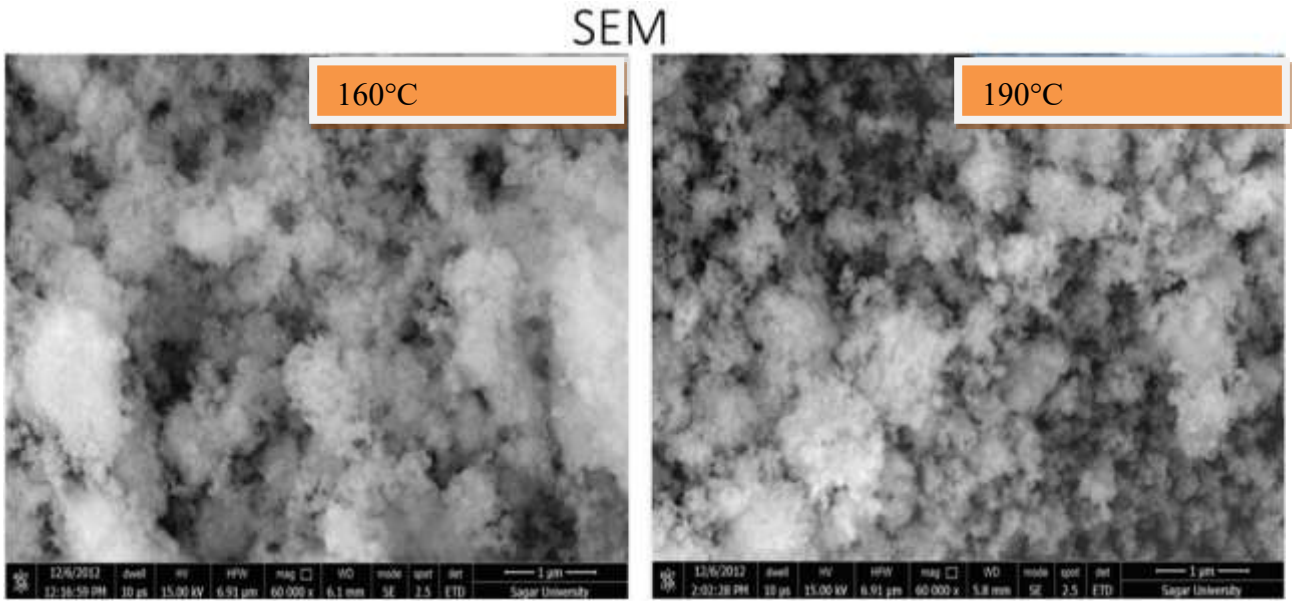

Figure 5 Results of the SEM analysis comparison

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In order to Justify the statement, Figure 6a) and Figure 6b) presentultraviolet UV-Visiblespectroscopy results for 160°C and at 190°C, respectively. Figure 6a shows a significant absorbance peak around 300 nm, followed by a gradual decrease in absorbance across the visible spectrum. Successful synthesis at 160°C is indicated by the La_2O_3 nanoparticle-specific peak at 300 nm in Figure 6a). On the other hand, Figure 6b) for La $(OH)_3$ at 190°C shows a less pronounced absorption curve. This discrepancy in spectrum patterns points to differences in the two samples particle size, shape, or makeup, which might be examined further using complementary analytical methods like transmission electron microscopy etc.

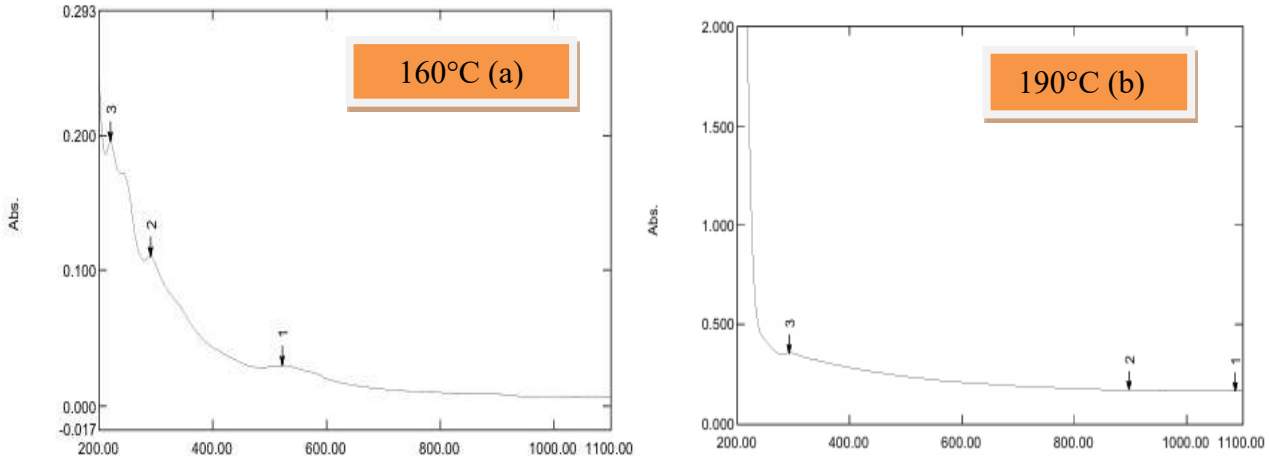

Figure 6(a,b) results of the UV-VISIBLE SPECTROSCOPY

Energy Dispersive X-ray Spectroscopy is an analytical technique used to characterize the elemental composition of materials, including nanoparticles. This section has presented the comparative analysis of the EDS analysis performed over the 160°C and 190°C temperatures for the proposed nanoparticles in conjunction to above shown SEM molecules. The Table 4 presents a comparison of atomic and weight concentrations of Lanthanum (La) and Oxygen (O) obtained from EDS analysis at two different low temperatures: 160°C and 190°C respectively. The data shows consistent results across both temperatures. The values so obtained are given in table 4. It is observed from the obtained data that with weight concentration of La increases while oxygen decreases.

Element Number	Element Name	Element Symbol	at 160 degree C			at 190 degree C		
			Atomic Concen. %	Weight Concen. %	Error in (wt%)	Atomic Concen. %	Weight Concen. %	Error in (wt%)
57	Lanthanum	La	23.76	73.01	1.66	25.89	75.20	1.79
8	Oxygen	O	76.24	26.99	2.99	74.11	24.81	2.88

Table 4 comparison of %Atomic concentration forEDS analysis at low temperatures

EDS can be used to create elemental maps of the sample, showing the distribution of different elements across the surface of the nanoparticles. This information can be vital for understanding how the properties of nanoparticles might vary spatially. The qualitative results are presented in the Figure 7(a,b) for the two cases of EDS at 160 °C and 190 °C respectively.

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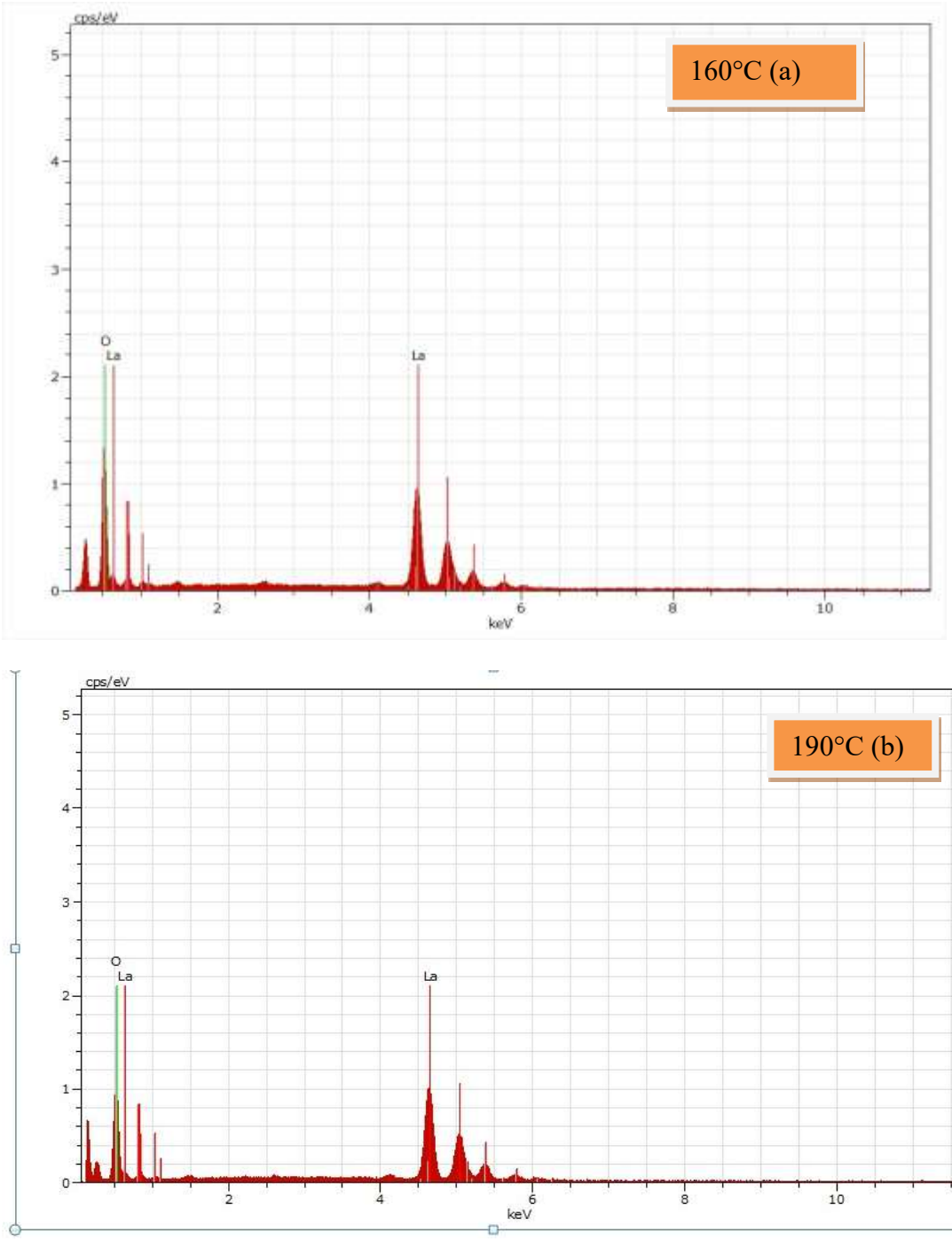

Figure 7(a,b) results of EDS spectrum of prepared samples

MACHINE LEARNING BASED PREDICTIONS AND ANALYSIS

This section presented the additional ML based MATLAB simulation to include X-ray Diffraction (XRD) characterization using the Debye-Scherrer formula, mechanical strain calculation, and crystalline parameters.This investigation includes specific parameters such as the shape factor K, X-ray wavelength λ, FWHM β, and the Bragg angle θ. The impact of the lowerβ factor is investigated and the respective ML based optimal strain and crystlline size is predicted. Table 5 presented the raw data used for the prediction of optimal β, strain ε, and Crystallite Size.

Beta Value	Crystallite Size @ 160°C (nm)	Mechanical Strain @ 160°C	Crystallite Size @ 190°C (nm)	Mechanical Strain @ 190°C
0.05	2.87	0.0467	2.87	0.0467
0.07	2.15	0.0622	2.15	0.0622
0.08	1.72	0.0778	1.72	0.0778
0.10	1.43	0.0933	1.43	0.0933
0.12	1.23	0.1089	1.23	0.1089
0.13	1.08	0.1244	1.08	0.1244
0.15	0.96	0.1400	0.96	0.1400
0.17	0.86	0.1555	0.86	0.1555
0.18	0.78	0.1711	0.78	0.1711
0.20	0.72	0.1866	0.72	0.1866

Table 5 Results of the ML based prediction of crystalline size and Strain

The linear regression model is applied over the data to predict the optimal size and strain. the mathematical made; is illustrated by

$$y = -0.0631x + 0.2038 \quad (4)$$

The third order prediction for polynomial regression is mathematically modelled as;

$$y = p_1x^2 + p_2x + p_3 \quad (5)$$

$$y = 0.0385x^2 + -0.1970x + 0.2986 \quad (6)$$

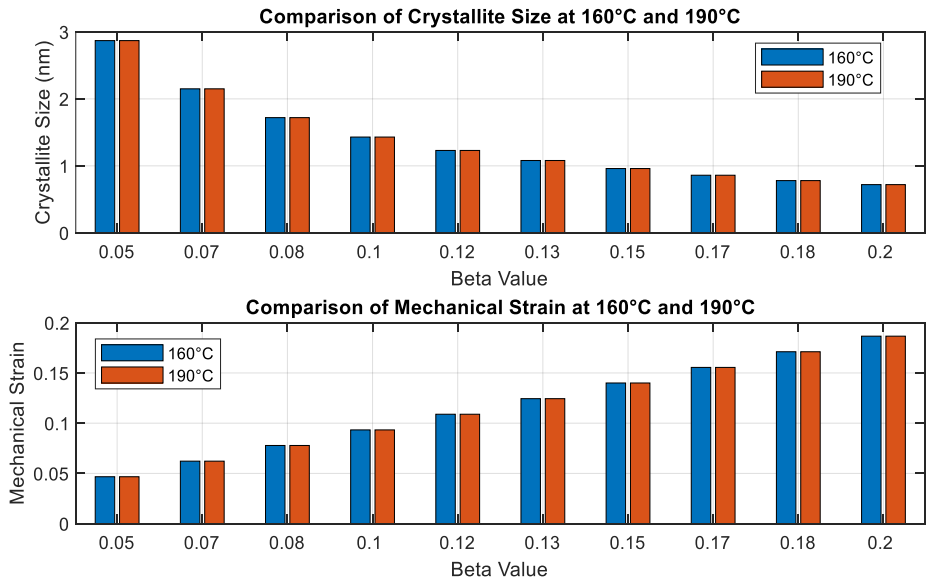

Figure 8: Comparative evaluation of the Beta value vs. crystalline size and strain.

It is found that strain and stress are inversely related to each other. The final predicted crystallite Size from ML Model for regression analysis is Beta = β=0.15 and the respective size is 1.06 nm.

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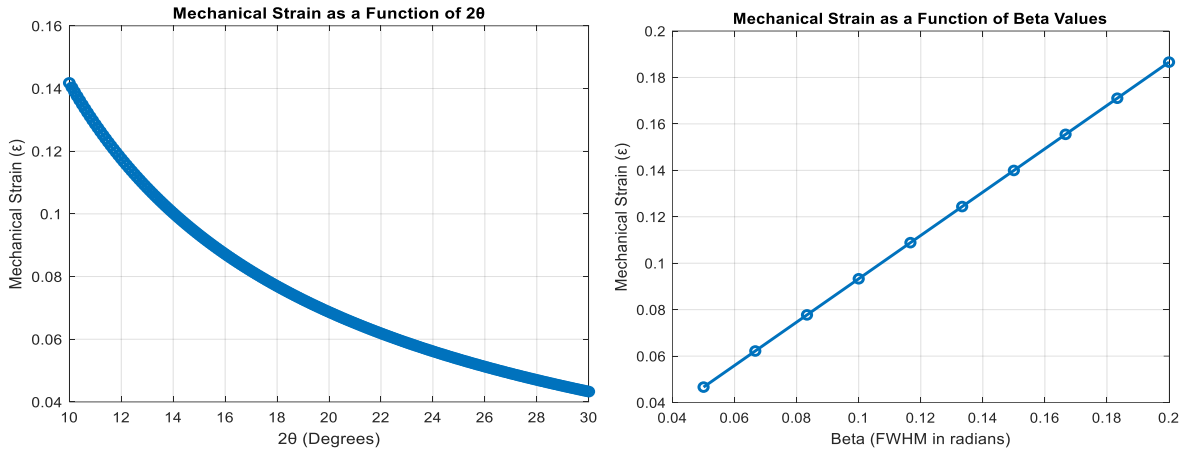

9a) for 2 Theta vs Mechanical Strain **9b) for β values Vs Mechanical Strain**

Figure 9 Investigation of ML based mechanical strain impacts on estimation results

Additionally, the MATLAB simulation in Figure 9 representing the result of investigation of ML based mechanical strain impacts. Figure 9a) shows a negative correlation between mechanical strain (ε) and 2θ (degrees). As 2θ increases, mechanical strain decreases.Figure 9b) displays a positive correlation between mechanical strain (ε) and β values (FWHM in radians). As β values increase, so does mechanical strain. The mechanical strain is related to the crystalline size as;

$$\varepsilon \propto \frac{1}{D} = \frac{K}{D} \qquad (7)$$

Where K is a constant, (related to dislocation density), D is the grain size. Thus, as an experiment in this work the β value is varied and respective strain vs crystalline size is predicted using the regression analysis. The Figure 10 presented the comparative predicted results vs actual results for the Linear and proposed polynomial regression model. In this work the third order regression is proposed as per the small set of data. It is clear from the Figure 10 that 3rd order regression or polynomial regression offers close approximation of the actual strain and size data.

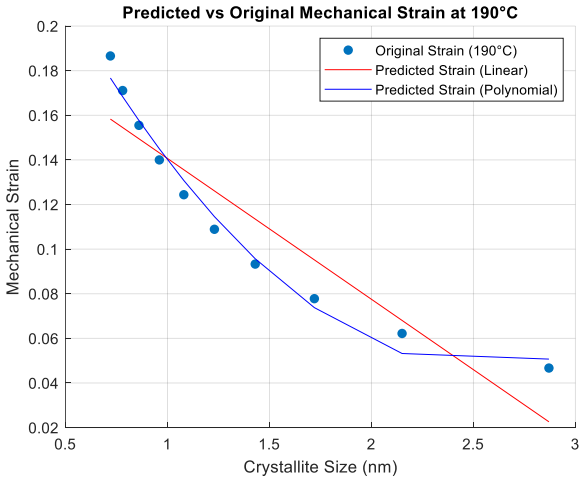

Figure 10Predicted Strain results vs actual results at 190^{O}C

The Table 6compares linear regression and polynomial regression in terms of parametric performance using metrics like R-squared, Mean Squared Error, and Sum of Squared Errors. The results show that polynomial regression significantly outperforms linear regression. Polynomial regression achieves a much higher R-squared value (0.9836) compared to linear regression (0.8562), indicating a substantially better fit to the data. Also, it achieves lower MSE and SSE values.

Method	R square	MSE	SSE
Linear regression	0.8562	2.8682e-04:	0.0171
Polynomial regression	0.9836	3.2628e-05	0.0196

Table 6: Parametric performance of prediction methods

6. CONCLUSIONS AND FUTURE SCOPES

In conclusion, this study successfully synthesized Lanthanum hydroxide and Lanthanum oxide nanoparticles using a simple co-precipitation method at room temperatures. The annealing temperature significantly influenced the morphology and properties of the nanoparticles. This cost-effective approach provides valuable insights into the structural, morphological, and compositional characteristics of nanoparticles, which can be beneficial for various applications in materials science and technology. In This study synthesized nano particles are having grain size 7.13nm and 7.92nm with mechanical strain0.0294 & 0.051133 respectively.FTIR spectroscopy confirmed the presence of La-O stretching modes, while SEM imaging showed agglomerated nanoparticles with morphological differences between samples synthesized at 160°C and 190°C. EDS analysis provided elemental composition data, with lanthanum and oxygen as the main constituents. The UV-Visible Spectroscopy revealed a significant absorbance peak around 300 nm in the La_2O_3 at 160°C.The annealing temperature was found to significantly impact the morphology, crystallinity, and properties of the resulting nanoparticles.

The ML-based MATLAB simulation was used to predict optimal strain and crystallite size following main conclusions are drawn from the investigation.

- The impact of different β factors on strain and crystallite size was investigated.
- Third-order polynomial regression significantly outperformed linear regression, achieving a higher R-squared value of 0.9836 compared to 0.8562, a lower Mean Squared Error of 3.2628e-05 versus 2.8682e-04, and a slightly better Sum of Squared Errors.
- Strain and stress were found to be inversely related to each other.

Further studies could explore how varying temperature profiles, precursor concentrations, and reaction times affect the properties of the La_2O_3nanoparticles. This could help optimize the synthesis process for specific applications.Research into scaling up the synthesis process while maintaining nanoparticle quality and reducing production costs could be valuable for industrial applications.

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