



IJRASET

International Journal For Research in
Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 **Issue:** XII **Month of publication:** December 2023

DOI: <https://doi.org/10.22214/ijraset.2023.57499>

www.ijraset.com

Call:  08813907089

E-mail ID: ijraset@gmail.com

Bimetal Enriched Carbon Nanomaterials Synthesized from *Bagasse*- A Plant Waste Material as an Exceptional Adsorbent for Hydrogen Gas

Bholanath T. Mukherjee¹, Suyash S. Prasad², Manoj D. Basutkar³

DSPM'S K.V. Pendharkar College, Dombivli, Maharashtra, India

Abstract: In this study, the process of pyrolysis has been depicted for the synthesis of CNMs from the *Bagasse*-a plant waste materials at high temperature of 750°C in an inert atmosphere. The Taguchi optimization methodology is utilized to optimize the parameters for synthesis process. The adsorption of hydrogen was investigated using Sievert's apparatus. The SEM image demonstrates the bimetal enriched CNMs and HRTEM reveals the CNMs obtained were in cylindrical form as well as transparent sheet. The presence of various bimetal combination is confirmed by EDAX. The spectroscopic studies XRD and Raman reveals the graphitic nature of the CNMs. 4.96 weight percent hydrogen adsorption was demonstrated by CNMs synthesized from *bagasse* under the parameters predicted by the Taguchi optimization methodology.

Keywords: Carbon nanomaterials, *Bagasse*, Taguchi optimization, Bimetal enriched, plant waste materials, Hydrogen adsorption, Sievert's apparatus.

I. INTRODUCTION

The need to find new, efficient energy sources has grown in recent years due to an energy shortage brought on by the depletion of energy supplies and environmental catastrophe. Hydrogen is a perfect solution for energy converters due to its high efficiency and significant contribution to reducing air pollution. Hydrogen an energy carrier that may be used to provide valuable thermal energy used in a variety of practical scientific applications without disrupting the environment or natural cycles[1][2][3][4]. Several distinct hydrogen storage systems, including liquefied hydrogen, compressed hydrogen, metal hydrides, and hydrogen physi-sorption on various substrates, including graphene materials and carbon nanomaterials (CNMs), have been proposed in recent years. [5][6][7][8][9].

Carbon materials is extremely encouraging among the numerous methods for storing hydrogen that have been researched thus far, since there is no chemical interaction between hydrogen and the surface of the materials utilized, providing completely reversible hydrogen and desorption[10][11][12][13]. Adsorption under encompassing circumstances on materials with uniform Van der Waals connections is believed to be able to meet the standards specified by the US Department of Energy (DOE) [14][15][16]. At room temperature, storing liquid hydrogen presents an explosion danger and is expensive. Metal hydride allows the ability to store hydrogen, but their substantial weight and inherently poor heat conductivity make the system uneconomical. A method of storing hydrogen using porous carbon materials has been developed to address these problems. [17][18][19][20][21][22]. Recently, both the academic and industrial sectors have paid close attention to carbon nanomaterials (CNMs), which have a large surface area, distinctive physical, mechanical, inherent high-aspect-ratio, hollow nano-geometry, among others [23][24][25][26][27]. Due to the physisorption and chemisorption processes involved, these materials have different hydrogen adsorption capabilities and inherent constraints [28][29][30][31]. Owing to the hydrogen spill-over effect, attaching or enriching CNMs with metal nanoparticles increases their capacity for storing hydrogen [32][33][34][35][36][37][38]. Nickel is a transition metal that is particularly promising for increasing hydrogen storage capacity since it is abundant and affordable compared to noble metals and is known metal for hydrogen catalysis [39], [40][41].

II. TAGUCHI METHODOLOGY

The goal of the current work was to standardize the pyrolysis of CNMs employing a horizontal furnace setup and plant waste materials (*Bagasse*) as precursors. This endeavour required a great deal of experimentation due to the consideration of several parameters and their variations. The Taguchi optimization approach was applied to tackle this issue. To obtain an understanding of the ideal conditions for obtaining the intended material, a large number of experiments have to be performed when four variable factors at three levels are to be employed.

In contrast, the Taguchi optimization technique requires an only a few experiments to be performed to obtain the same knowledge. The Taguchi optimization technique's specifics are covered separately in the following references-[42] [43] [44] [45] [46] [47].

III. EXPERIMENTAL TECHNIQUES

A. Synthesis of Carbon nanomaterials (CNMs) from Bagasse- a Plant Waste Material

The bagasse (*Saccharum officinarum*) fibers that were extracted from the plant waste materials were carbonized at 750°C in an inert atmosphere using a Lindberg horizontal quartz tube furnace. The carbon materials obtained were activated using various concentrations of alkali solutions as mentioned in Table 1. The activated carbons were loaded with Ni-Li, Ni-Mg and Ni-Al nanoparticles combinations. The resulting CNMs were then used to investigate the properties of hydrogen adsorption using Sievert's apparatus.

B. Determination of Hydrogen Adsorption

For the investigation 10 grams (approx.) of CNMs were utilized. Using Sievert's apparatus and the static volumetric technique, the hydrogen adsorption isotherms were measured at room temperature. Mukherjee et al. [40], [48] ,[49] have used Sievert's apparatus to study hydrogen adsorption on CNMs at a pressure about 60 bar.

TABLE 1: HYDROGEN ADSORPTION BY BIMETAL ENRICHED CNMs (TAGUCHI ORTHOGONAL TABLE)

Experiments	Alkali-treatment	Bimetal loaded	Duration of annealing (Hr.)	Temperature (°C)	ADS wt. %
L1	NaOH	Ni-Li	2	600	3.0879
L2	NaOH	Ni-Mg	2.5	700	2.2633
L3	NaOH	Ni-Al	3	800	3.1768
L4	Na ₂ CO ₃	Ni-Li	2.5	800	3.2561
L5	Na ₂ CO ₃	Ni-Mg	3	600	3.1473
L6	Na ₂ CO ₃	Ni-Al	2	700	3.2516
L7	K₂CO₃	Ni-Li	3	700	4.9295
L8	K ₂ CO ₃	Ni-Mg	2	800	4.8368
L9	K ₂ CO ₃	Ni-Al	2.5	600	3.6397

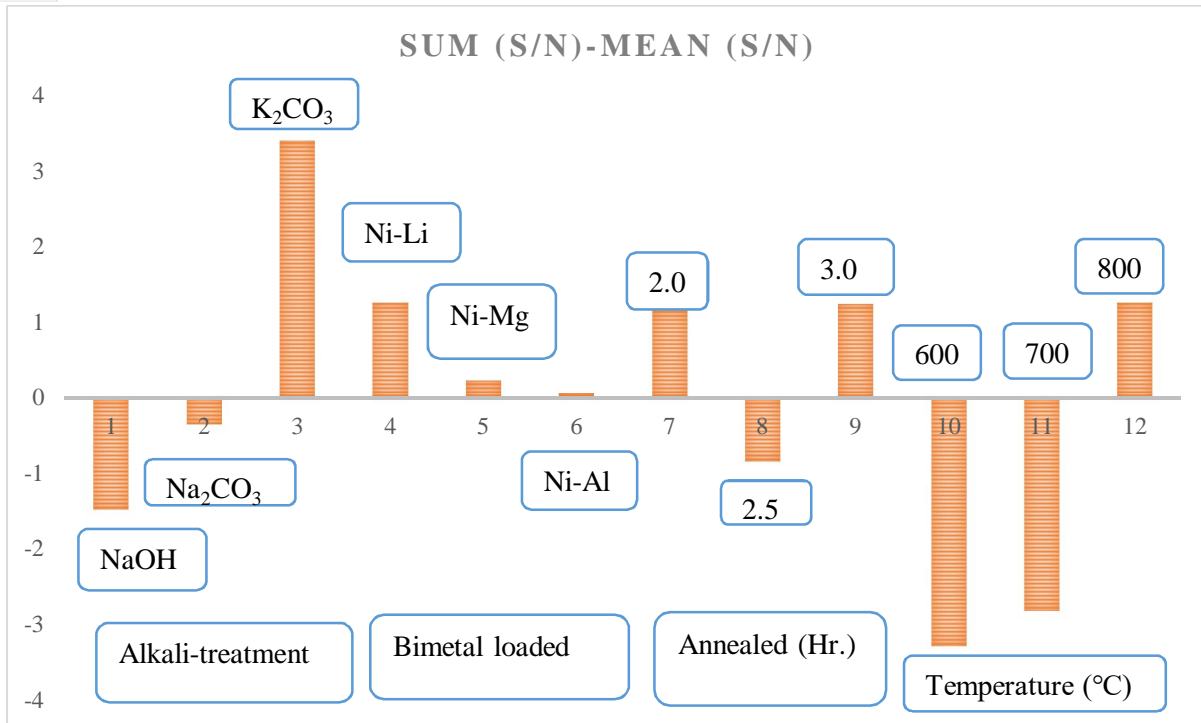


Fig.1 Histogram of sum (S/N) – mean (S/N) for synthesis of CNMs

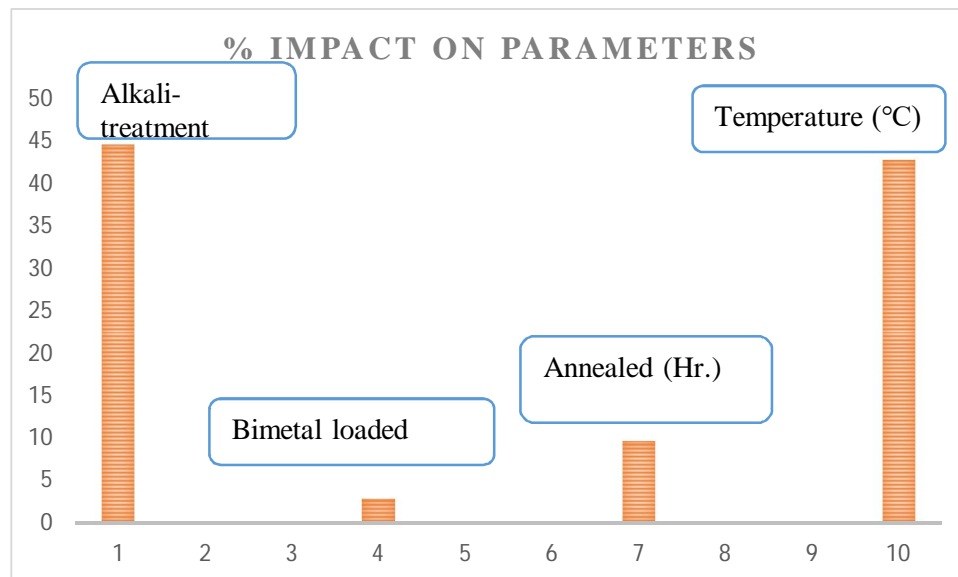


Fig.2 Histogram presenting % impact of different parameters on hydrogen adsorption by CNMs

The above histogram shows that the best results for hydrogen adsorption could be obtained when the bagasse is treated with K_2CO_3 loaded with bimetal Ni-Li combination and annealing for 3 hours at a temperature of 800 °C. These conditions are comparable to those of L7, with the exception that temperature is required at 800 °C as opposed to 700 °C (Table 1). This is actually the benefit of Taguchi Optimization—it can forecast the optimal outcome even when the experiment may not have been conducted in that manner. To determine which factor or factors need to be monitored for better results, a histogram of the % impact of various parameters was also plotted (Fig.2). It is clear from the histogram (Fig.2) the percentage impact of the parameters that using alkali K_2CO_3 is the most crucial step in obtaining the carbon with the highest hydrogen adsorption capacity (44.64%). Additionally, the impact of bimetal is minimal with 3.90%.

The duration of annealing has a percentage effect of 2.89% whereas the temperature has the percentage effect of 42.79% on the sample. This suggests that a different temperature range needs to be investigated. Figure 1 suggests that the temperature to be at 800 °C, but L7 demonstrates that carbon synthesized at 700 °C has the maximum hydrogen adsorption capacity. To determine the optimal pyrolysis, it is evident that a thorough investigation of the effects of temperature between 750 and 850 °C is necessary.

C. Validation of Best Parameter Projected by Taguchi Optimization Methodology

It was necessary to conduct the experiments under the conditions predicted by the Taguchi optimization methodology because the first set of experiments (Table 1) did not follow the experimental conditions predicted by the Taguchi optimization methodology. The extension of above Taguchi (Table 1) was built in the manner indicated in following Table 2. The annealing process was run for 2.5 and 3.0 hours at a temperature between 750 and 850°C. The CNMs prepared from bagasse sample was given an alkali treatment using K₂CO₃ and loading of Ni-Li combination as it was the conditions predicted by the Taguchi Optimization methodology which revealed the highest observed hydrogen adsorption (Table 2). The maximum adsorption under these circumstances is 4.96 weight percent, surpassing the results of all L9 experiments (Table 1, L7: 4.92 weight percent).

Table 2: Outcomes of extension for Taguchi (Table 1)

Sr. No.	Duration of annealing (Hr.)	Temperature (°C)	ADS wt. %
1	2.5	750	4.1952
2	3	750	4.8570
3	2.5	800	3.8353
4	3	800	4.9634
5	2.5	850	3.7966
6	3	850	3.6646

IV. RESULTS AND DISCUSSIONS

A. Characterisation of CNMs

Using a Scanning Electron Microscopy (SEM) image, the microstructure and morphology of the carbon nanomaterial were examined [50] [51] [52][53][54]. The SEM image demonstrates the bimetal enriched CNMs made from plant waste materials. The CNMs are porous and have an average pores size between 35 and 60 nm [Fig.3 (a)]. Typically, amorphous carbon and carbon nanofibers with a disordered structure are combined to create the CNM [55] [Fig.3(b)].

The microscopic techniques to study the structure and the properties of the CNMs, the HRTEM was similarly used for the visualization of the samples [56] [57]. HRTEM reveals the CNMs obtained are in cylindrical form [Fig.3 (c)] as well as transparent sheet type [Fig.3 (d)]. The TEM image correspondingly demonstrates the bimetal enriched CNMs uniformly distributed in the diameter ranging from 15nm to 20nm [Fig.3 (c) and (d)]. The surface area was analyzed by BET (Brunauer-Emmett-Teller) [58] [59] and was found to be 517.875 m²g⁻¹ [Fig.5 (a)] and 0.220 cc/g [Fig.5 (b)] as a pore volume of the CNMs.

B. Spectroscopic Studies

X-Ray Diffraction (XRD) techniques [60], [61] [61] [62] [63] are used to analyze the final CNMs that are obtained after annealing [Fig. 4 (a)]. Two theta values were obtained: one sharp peak at 26.21, corresponding to the (002) plane along with 43.74 and 44.28 corresponding to the (100) plane which suggest graphitic and partial crystalline nature of carbon nano materials.

Crystallographic orientation of the CNMs was also studied using Raman spectroscopy [64] [65] [66] [67] [68] [69] [70]. A Raman spectrum [Fig.4 (b)] displays one peak at 2594 cm⁻¹ and another at 3180 cm⁻¹ which states the second order D-band, also known as the 2D-band, is dependent on the packing in three-dimensional space, also is associated with the boundary point K in the graphite's Brillouin zone that divulges the graphitic nature of the materials having disordered carbon [71]. Furthermore, the peaks at 2594 cm⁻¹ result from the CH₂ group's symmetric and asymmetric C-H stretching vibrations and the peak at 3180 cm⁻¹ is produced due to one phonon lattice vibrational process.

Energy-dispersive X-ray analysis (EDAX) of samples [Fig.6 (a) (b) (c)] indicates the various bimetal combinations utilized for the enrichment of the CNMs.

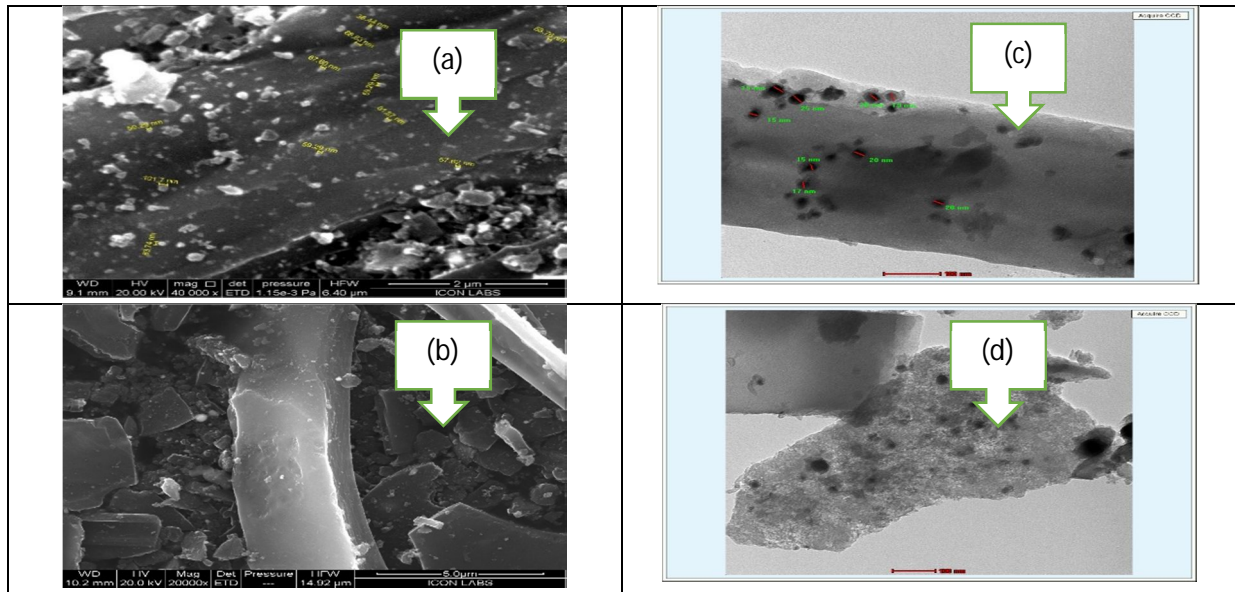


Fig.3 CNMs obtained by pyrolysis of bagasse-a plant waste materials [(a) and (b) Scanning Electron Microscopy (SEM) of bimetal enriched samples]; (c) and (d) High-Resolution Transmission Electron Microscopy (HRTEM) of cylindrical and transparent sheet of CNMs.

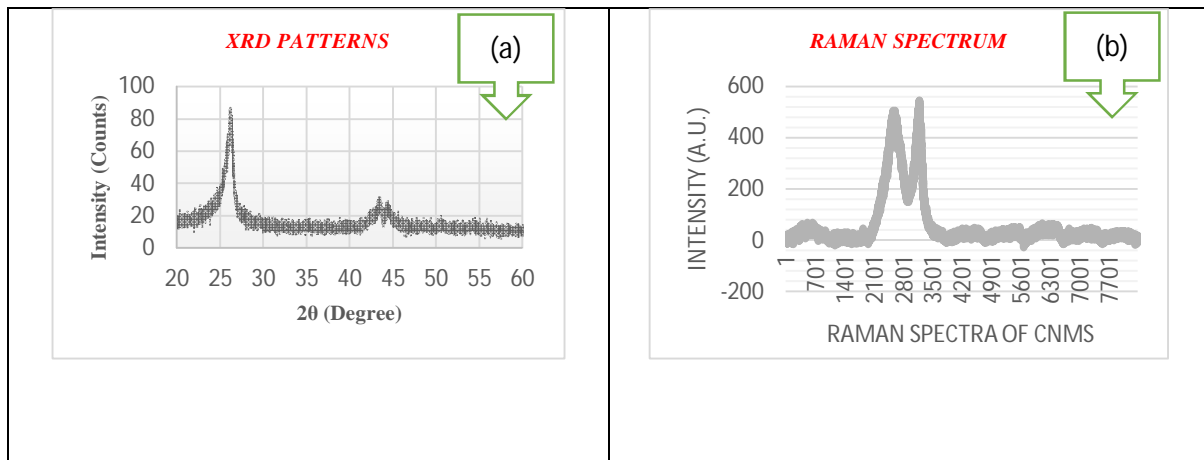


Fig.4 Spectroscopic studies

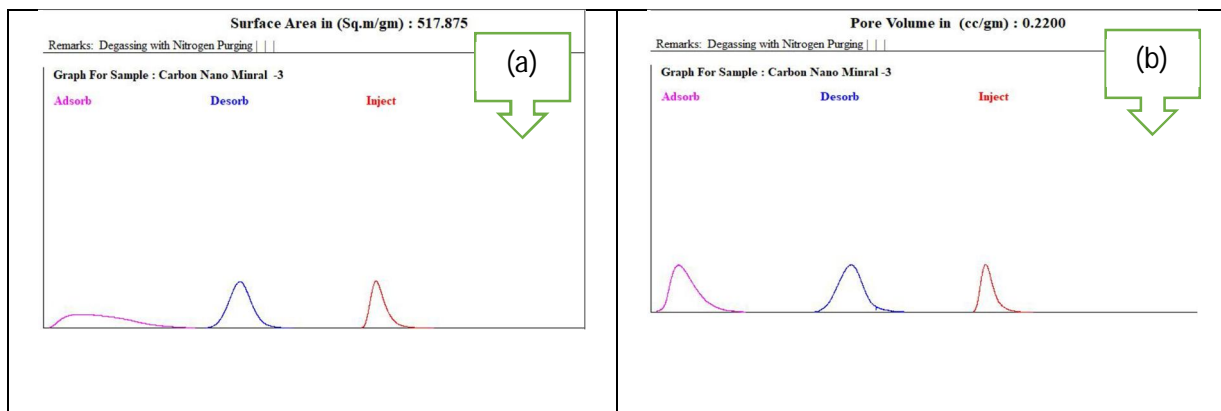


Fig.5 BET of CNMs

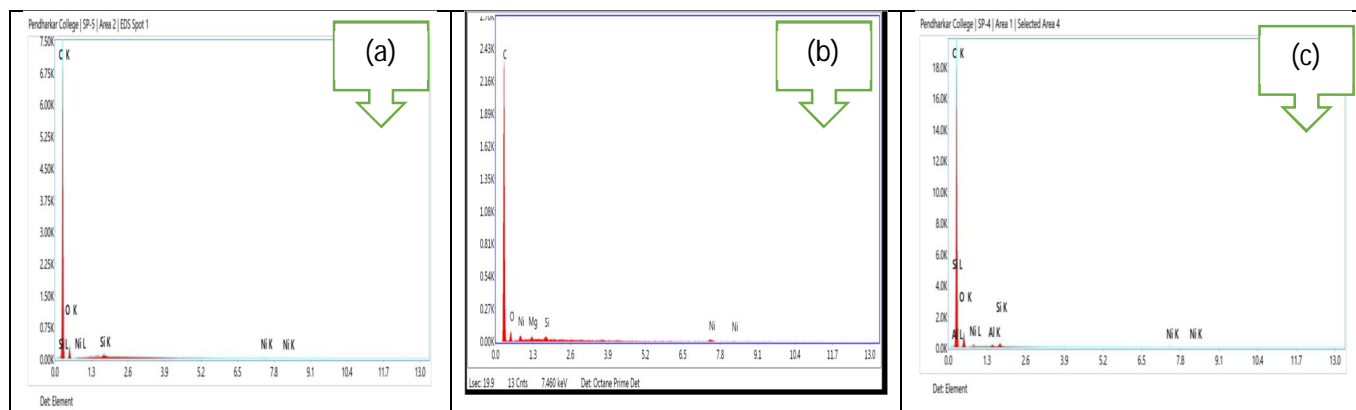


Fig.6 EDAX of CNMs

V. CONCLUSION

The maximum hydrogen adsorption capacity of 4.96 weight percent was achieved when pyrolyzed bagasse sample was given alkali treatment using K_2CO_3 followed by bimetal loading of Ni-Li combination annealed for 3 hours at a temperature of 800 °C as predicted by Taguchi optimization methodology. The CNMs thus obtained by above mentioned process is found to be cylindrical as well as transparent with graphitic properties.

REFERENCES

- [1] L. Schlapbach and A. Züttel, "Hydrogen-storage materials for mobile applications," 2001. [Online]. Available: www.nature.com
- [2] C. Liu, Y. Y. Fan, M. Liu, H. T. Cong, H. M. Cheng, and M. S. Dresselhaus, "Hydrogen storage in single-walled carbon nanotubes at room temperature," *Science* (1979), vol. 286, no. 5442, pp. 1127–1129, Nov. 1999, doi: 10.1126/science.286.5442.1127.
- [3] N. L. Rosi et al., "Hydrogen storage in microporous metal-organic frameworks," *Science* (1979), vol. 300, no. 5622, pp. 1127–1129, May 2003, doi: 10.1126/science.1083440.
- [4] K. Xia, J. Hu, and J. Jiang, "Enhanced room-temperature hydrogen storage in super-activated carbons: The role of porosity development by activation," *Appl Surf Sci*, vol. 315, no. 1, pp. 261–267, 2014, doi: 10.1016/j.apsusc.2014.07.144.
- [5] S. Fukuzumi and T. Suenobu, "Hydrogen storage and evolution catalysed by metal hydride complexes," *Dalton Transactions*, vol. 42, no. 1, pp. 18–28, Jan. 07, 2013. doi: 10.1039/c2dt31823g.
- [6] K. P. Brooks, T. A. Semelsberger, K. L. Simmons, and B. van Hassel, "Slurry-based chemical hydrogen storage systems for automotive fuel cell applications," *J Power Sources*, vol. 268, pp. 950–959, Dec. 2014, doi: 10.1016/j.jpowsour.2014.05.145.
- [7] M. U. Niemann, S. S. Srinivasan, A. R. Phani, A. Kumar, D. Y. Goswami, and E. K. Stefanakos, "Nanomaterials for hydrogen storage applications: A review," *J Nanomater*, vol. 2008, no. 1, 2008, doi: 10.1155/2008/950967.
- [8] M. B. Ley et al., "Complex hydrides for hydrogen storage - New perspectives," *Materials Today*, vol. 17, no. 3, Elsevier B.V., pp. 122–128, 2014. doi: 10.1016/j.mattod.2014.02.013.
- [9] D. Silambarasan, V. J. Surya, V. Vasu, and K. Iyakutti, "Single walled carbon nanotube-metal oxide nanocomposites for reversible and reproducible storage of hydrogen," *ACS Appl Mater Interfaces*, vol. 5, no. 21, pp. 11419–11426, Nov. 2013, doi: 10.1021/am403662t.
- [10] B. Panella, M. Hirscher, and S. Roth, "Hydrogen adsorption in different carbon nanostructures," *Carbon N Y*, vol. 43, no. 10, pp. 2209–2214, 2005, doi: 10.1016/j.carbon.2005.03.037.
- [11] S. Sircar, T. C. Golden, and M. B. Rao, "Activated carbon for gas separation and storage," *Carbon N Y*, vol. 34, no. 1, pp. 1–12, 1996, doi: 10.1016/0008-6223(95)00128-X.
- [12] M. Rzepka, P. Lamp, and M. A. De La Casa-Lillo, "Physisorption of hydrogen on microporous carbon and carbon nanotubes," *Journal of Physical Chemistry B*, vol. 102, no. 52, pp. 10894–10898, 1998, doi: 10.1021/jp9829602.
- [13] P. Bénard and R. Chahine, "Storage of hydrogen by physisorption on carbon and nanostructured materials," *Scr Mater*, vol. 56, no. 10, pp. 803–808, 2007, doi: 10.1016/j.scriptamat.2007.01.008.
- [14] G. K. Dimitrakakis, E. Tylianakis, and G. E. Froudakis, "Pillared graphene: a new 3-D network nanostructure for enhanced hydrogen storage," *Nano Lett*, vol. 8, no. 10, pp. 3166–3170, 2008, doi: 10.1021/nl801417w.
- [15] K. Sumida et al., "Impact of metal and anion substitutions on the hydrogen storage properties of M-BTT metal-organic frameworks," *J Am Chem Soc*, vol. 135, no. 3, pp. 1083–1091, 2013, doi: 10.1021/ja310173e.
- [16] M. A. Salam, S. Sufian, and T. Murugesan, "Hydrogen storage investigation of fixed bed of nano-crystalline Mg-Ni-Cr mixed oxides," *Adv Mat Res*, vol. 701, pp. 179–183, 2013, doi: 10.4028/www.scientific.net/AMR.701.179.
- [17] M. J. Jung, J. W. Kim, J. S. Im, S. J. Park, and Y. S. Lee, "Nitrogen and hydrogen adsorption of activated carbon fibers modified by fluorination," *Journal of Industrial and Engineering Chemistry*, vol. 15, no. 3, pp. 410–414, May 2009, doi: 10.1016/j.jiec.2008.11.001.

- [18] B. Mukherjee, G. Kalita, M. Sharon, and M. Sharon, "Hydrogen storage by carbon fibers from cotton," QScience Connect, no. 2013, p. 45, Mar. 2013, doi: 10.5339/connect.2013.45.
- [19] N. C. Gallego and T. D. Burchell, "Carbon materials for hydrogen storage," Global 2003: Atoms for Prosperity: Updating Eisenhowers Global Vision for Nuclear Energy, pp. 1185–1187, 2003.
- [20] N. Rajalakshmi, B. Y. Sarada, and K. S. Dhathathreyan, "Porous Carbon Nanomaterial from Corncob as Hydrogen Storage Material," Advanced Porous Materials, vol. 2, no. 3, pp. 165–170, 2015, doi: 10.1166/apm.2014.1068.
- [21] J. Sakamoto, J. Nakayama, T. Nakarai, N. Kasai, T. Shibutani, and A. Miyake, "Effect of gasoline pool fire on liquid hydrogen storage tank in hybrid hydrogen-gasoline fueling station," Int J Hydrogen Energy, vol. 41, no. 3, pp. 2096–2104, Jan. 2016, doi: 10.1016/j.ijhydene.2015.11.039.
- [22] O. Hemmers et al., "IV . G . 1 Hydrogen Fuel Cells and Storage Technology Project (FCAST) IV . G . 1 Hydrogen Fuel Cells and Storage Technology Project (FCAST)*, " no. February 2014.
- [23] A. Klechikov, G. Mercier, T. Sharifi, I. A. Baburin, G. Seifert, and A. v Talyzin, "Hydrogen storage in high surface area graphene scaffolds," 2015.
- [24] A. Ghedjatti et al., "Structural Properties of Double-Walled Carbon Nanotubes Driven by Mechanical Interlayer Coupling," ACS Nano, vol. 11, no. 5, pp. 4840–4847, 2017, doi: 10.1021/acsnano.7b01328.
- [25] V. Fierro et al., "Experimental evidence of an upper limit for hydrogen storage at 77 K on activated carbons," Carbon N Y, vol. 48, no. 7, pp. 1902–1911, 2010, doi: 10.1016/j.carbon.2010.01.052.
- [26] J. L. Delgado, M. Á. Herranz, and N. Martín, "The nano-forms of carbon," J Mater Chem, vol. 18, no. 13, pp. 1417–1426, 2008, doi: 10.1039/b717218d.
- [27] E. Boateng and A. Chen, "Recent advances in nanomaterial-based solid-state hydrogen storage," Mater Today Adv, vol. 6, Jun. 2020, doi: 10.1016/j.mtadv.2019.100022.
- [28] M. Sharon et al., "Hydrogen storage by carbon materials synthesized from oil seeds and fibrous plant materials," Int J Hydrogen Energy, vol. 32, no. 17, pp. 4238–4249, 2007, doi: 10.1016/j.ijhydene.2007.05.038.
- [29] M. Doğan, P. Sabaz, Z. Bicil, B. Koçer Kizilduman, and Y. Turhan, "Activated carbon synthesis from tangerine peel and its use in hydrogen storage," Journal of the Energy Institute, vol. 93, no. 6, pp. 2176–2185, 2020, doi: 10.1016/j.joei.2020.05.011.
- [30] L. L. Vasiliev, L. E. Kanonchik, A. G. Kulakov, and D. A. Mishkinis, "Activated carbon and hydrogen adsorption storage," NATO Security through Science Series A: Chemistry and Biology, pp. 633–651, 2007, doi: 10.1007/978-1-4020-5514-0_80.
- [31] V. Dhand, J. S. Prasad, K. Y. Rhee, and Y. Anjaneyulu, "Fabrication of high pressure hydrogen adsorption/desorption unit-Adsorption study on flame synthesized carbon nanofibers," Journal of Industrial and Engineering Chemistry, vol. 19, no. 3, pp. 944–949, 2013, doi: 10.1016/j.jiec.2012.11.013.
- [32] H. Zhou, X. Liu, J. Zhang, X. Yan, Y. Liu, and A. Yuan, "Enhanced room-temperature hydrogen storage capacity in Pt-loaded graphene oxide/HKUST-1 composites," Int J Hydrogen Energy, vol. 39, no. 5, pp. 2160–2167, Feb. 2014, doi: 10.1016/j.ijhydene.2013.11.109.
- [33] R. Juarez-Mosqueda, A. Mavrandonakis, A. B. Kuc, L. G. M. Pettersson, and T. Heine, "Theoretical analysis of hydrogen spillover mechanism on carbon nanotubes," Front Chem, vol. 3, no. FEB, 2015, doi: 10.3389/fchem.2015.00002.
- [34] S. Z. Mortazavi, P. Parvin, A. Reyhani, R. Malekfar, and S. Mirershadi, "Hydrogen storage property of laser induced Pd-nanoparticle decorated multi-walled carbon nanotubes," RSC Adv, vol. 3, no. 5, pp. 1397–1409, Feb. 2013, doi: 10.1039/c2ra22224h.
- [35] T. A. Maark and S. Pal, "A model study of effect of M = Li+, Na+, Be 2+, Mg2+, and Al3+ ion decoration on hydrogen adsorption of metal-organic framework-5," Int J Hydrogen Energy, vol. 35, no. 23, pp. 12846–12857, Dec. 2010, doi: 10.1016/j.ijhydene.2010.08.054.
- [36] S. Seenithurai, R. K. Pandyan, S. V. Kumar, C. Saranya, and M. Mahendran, "Al-decorated carbon nanotube as the molecular hydrogen storage medium," Int J Hydrogen Energy, vol. 39, no. 23, pp. 11990–11998, 2014, doi: 10.1016/j.ijhydene.2014.05.184.
- [37] P. Chen, X. Wu, J. Lin, and K. L. Tan, "High H2 uptake by alkali-doped carbon nanotubes under ambient pressure and moderate temperatures," Science (1979), vol. 285, no. 5424, pp. 91–93, 1999, doi: 10.1126/science.285.5424.91.
- [38] S. Seenithurai, R. K. Pandyan, S. V. Kumar, C. Saranya, and M. Mahendran, "Li-decorated double vacancy graphene for hydrogen storage application: A first principles study," Int J Hydrogen Energy, vol. 39, no. 21, pp. 11016–11026, Jul. 2014, doi: 10.1016/j.ijhydene.2014.05.068.
- [39] M. Sharon, M. Sharon, G. Kalita, and B. Mukherjee, "Hydrogen Storage by Carbon Fibers Synthesized by Pyrolysis of Cotton Fibers," Carbon letters, vol. 12, no. 1, pp. 39–43, Mar. 2011, doi: 10.5714/cl.2011.12.1.039.
- [40] B. Mukherjee, M. Sharon, G. Kalita, and M. Sharon, "Ambiguity in determining H2 adsorption capacity of carbon fiber by pressure technique," Int J Hydrogen Energy, vol. 41, no. 4, pp. 2671–2676, Jan. 2016, doi: 10.1016/j.ijhydene.2015.12.110.
- [41] B. T. Mukherjee, ; S K Sainik, and ; K R Jagdeo, "Microwave absorption by CNM decorated with nickel nano particles," 2017. [Online]. Available: [www.ijesi.org](http://www.ijesi.org/Volumewww.ijesi.org)
- [42] M. Sharon, R. Kumar, and A. K. Choudhary, "Optimization of parameters by Taguchi optimization method and synthesis of carbon nano materials (CNM) from oil rich non-edible seeds using chemical vapour deposition technique," International Journal of Advances in Engineering and Management (IJAEM), vol. 2, no. 8, p. 288, 2008, doi: 10.35629/5252-0208288298.
- [43] S. Maheshwar, S. Madhuri, K. Golap, and M. Bholanath, "Hydrogen Storage by Carbon Fibers Synthesized by Pyrolysis of Cotton Fibers," Carbon letters, vol. 12, no. 1, pp. 39–43, Mar. 2011, doi: 10.5714/CL.2011.12.1.039.
- [44] V. N. Nair, "Taguchis parameter design: A panel discussion," Technometrics, vol. 34, no. 2, pp. 127–161, 1992, doi: 10.1080/00401706.1992.10484904.
- [45] H. Atil and Y. Unver, "A Different Approach of Experimental Design: Taguchi Method," Pakistan Journal of Biological Sciences, vol. 3, no. 9, pp. 1538–1540, 2000.
- [46] K. L. Tsui, "AN OVERVIEW OF TAGUCHI METHOD AND NEWLY DEVELOPED STATISTICAL METHODS FOR ROBUST DESIGN," <https://doi.org/10.1080/07408179208964244>, vol. 24, no. 5, pp. 44–57, 2007, doi: 10.1080/07408179208964244.
- [47] R. H. Lochner and J. E. Matar, Designing for quality : an introduction to the best of Taguchi and western methods of statistical experimental design. Quality Resources, 1990. Accessed: Jun. 29, 2023. [Online]. Available: <https://link.springer.com/book/9780412400209>
- [48] B. Mukherjee, "Carbon Nanofiber for Hydrogen Storage," Carbon Nanofibers: Fundamentals and Applications, pp. 175–209, Jan. 2021, doi: 10.1002/9781119769149.CH7.
- [49] S. S. Prasad, S. K. Sainik, M. D. Basutkar, and B. T. Mukherjee, "Bimetal Decorated Carbon Nano Materials (CNMs) Synthesized from Plant Waste Materials as An Excellent Hydrogen Storage Material," Int J Res Appl Sci Eng Technol, vol. 10, no. 10, pp. 1–4, Oct. 2022, doi: 10.22214/ijraset.2022.46931.

- [50] W. Zhou, R. Apkarian, Z. L. Wang, and D. Joy, "Fundamentals of scanning electron microscopy (SEM)," *Scanning Microscopy for Nanotechnology: Techniques and Applications*, pp. 1–40, 2007, doi: 10.1007/978-0-387-39620-0_1/COVER.
- [51] N. Ural, "The significance of scanning electron microscopy (SEM) analysis on the microstructure of improved clay: An overview," *Open Geosciences*, vol. 13, no. 1, pp. 197–218, Jan. 2021, doi: 10.1515/GEO-2020-0145/ASSET/GRAPHIC/J_GEO-2020-0145_FIG_024.JPG.
- [52] A. Mohammed and A. Abdullah, "SCANNING ELECTRON MICROSCOPY (SEM): A REVIEW".
- [53] G. Thomas, "Modern electron microscopy for materials characterization," *J Electron Microscop Tech*, vol. 3, no. 1, pp. 95–108, 1986, doi: 10.1002/jemt.1060030109.
- [54] B. J. Inkson, "Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) for materials characterization," *Materials Characterization Using Nondestructive Evaluation (NDE) Methods*, pp. 17–43, Jan. 2016, doi: 10.1016/B978-0-08-100040-3.00002-X.
- [55] J. F. Colomer et al., "Large-scale synthesis of single-wall carbon nanotubes by catalytic chemical vapor deposition (CCVD) method," *Chem Phys Lett*, vol. 317, no. 1–2, pp. 83–89, 2000, doi: 10.1016/S0009-2614(99)01338-X.
- [56] D. B. Williams and C. B. Carter, "The Transmission Electron Microscope," *Transmission Electron Microscopy*, pp. 3–17, 1996, doi: 10.1007/978-1-4757-2519-3_1.
- [57] M. Winey, J. B. Meehl, E. T. O'Toole, and T. H. Giddings, "Conventional transmission electron microscopy," *Mol Biol Cell*, vol. 25, no. 3, pp. 319–323, Feb. 2014, doi: 10.1091/MBC.E12-12-0863/ASSET/IMAGES/LARGE/319FIG2.JPEG.
- [58] M. Naderi, "Surface Area: Brunauer–Emmett–Teller (BET)," *Progress in Filtration and Separation*, pp. 585–608, Jan. 2015, doi: 10.1016/B978-0-12-384746-1.00014-8.
- [59] G. Fagerlund, "Determination of specific surface by the BET method," *Matériaux et Constructions*, vol. 6, no. 3, pp. 239–245, May 1973, doi: 10.1007/BF02479039/METRICS.
- [60] J. Epp, "X-ray diffraction (XRD) techniques for materials characterization," *Materials Characterization Using Nondestructive Evaluation (NDE) Methods*, pp. 81–124, Jan. 2016, doi: 10.1016/B978-0-08-100040-3.00004-3.
- [61] L. R. B. Elton and D. F. Jackson, "X-Ray Diffraction and the Bragg Law," *Am J Phys*, vol. 34, no. 11, pp. 1036–1038, Nov. 1966, doi: 10.1119/1.1972439.
- [62] A. Ahmad et al., "Role of XRD for nanomaterial analysis," *Nanomedicine Manufacturing and Applications*, pp. 149–161, Jan. 2021, doi: 10.1016/B978-0-12-820773-4.00008-1.
- [63] S. Fatimah, R. Ragadhita, D. F. Al Husaeni, and A. B. D. Nandiyanto, "How to Calculate Crystallite Size from X-Ray Diffraction (XRD) using Scherrer Method," *ASEAN Journal of Science and Engineering*, vol. 2, no. 1, pp. 65–76, Mar. 2022, doi: 10.17509/AJSE.V2I1.37647.
- [64] J. Schwan, S. Ulrich, V. Batori, H. Ehrhardt, and S. R. P. Silva, "Raman spectroscopy on amorphous carbon films," *J Appl Phys*, vol. 80, no. 1, pp. 440–447, Jul. 1996, doi: 10.1063/1.362745.
- [65] D. Cialla-May, M. Schmitt, and J. Popp, "Theoretical principles of Raman spectroscopy," *Physical Sciences Reviews*, vol. 4, no. 6, Jun. 2019, doi: 10.1515/PSR-2017-0040/MACHINEREADABLECITATION/RIS.
- [66] M. S. Dresselhaus, G. Dresselhaus, R. Saito, and A. Jorio, "Raman spectroscopy of carbon nanotubes," *Phys Rep*, vol. 409, no. 2, pp. 47–99, Mar. 2005, doi: 10.1016/J.PHYSREP.2004.10.006.
- [67] Y. Wang, D. C. Alsmeyer, and R. L. McCreery, "Raman Spectroscopy of Carbon Materials: Structural Basis of Observed Spectra," *Chemistry of Materials*, vol. 2, no. 5, pp. 557–563, Sep. 1990, doi: 10.1021/CM00011A018/ASSET/CM00011A018.FP.PNG_V03.
- [68] J. Dennison, M. Holtz, and G. Swain, "Raman Spectroscopy of Carbon Materials," *Spectroscopy*, vol. 11, no. 8, Jan. 1996, Accessed: Jul. 29, 2023. [Online]. Available: https://digitalcommons.usu.edu/mp_facpub/26
- [69] R. Escribano, J. J. Sloan, N. Siddique, N. Sze, and T. Dudev, "Raman spectroscopy of carbon-containing particles," *Vib Spectrosc*, vol. 26, no. 2, pp. 179–186, Nov. 2001, doi: 10.1016/S0924-2031(01)00106-0.
- [70] M. S. Dresselhaus, G. Dresselhaus, and A. Jorio, "Raman Spectroscopy of Carbon Nanotubes in 1997 and 2007†," *Journal of Physical Chemistry C*, vol. 111, no. 48, pp. 17887–17893, Dec. 2007, doi: 10.1021/JP071378N.
- [71] L. Bokobza, J.-L. Bruneel, and M. Couzi, "Raman Spectra of Carbon-Based Materials (from Graphite to Carbon Black) and of Some Silicone Composites," *C (Basel)*, vol. 1, no. 1, pp. 77–94, Dec. 2015, doi: 10.3390/c1010077



10.22214/IJRASET



45.98



IMPACT FACTOR:
7.129



IMPACT FACTOR:
7.429



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Call : 08813907089  (24*7 Support on Whatsapp)