

STUDY OF THE PROPERTIES AND APPLICATIONS OF NANOMATERIALS, INCLUDING NANOTUBES, NANOWIRES, AND GRAPHENE

Syed Rizwan Hussain^{1*}, Muhammad Yousaf Hamza²

¹HoD Physics & Astronomy, NUST School of Natural Sciences, Islamabad (NUST School of Natural Sciences)

²Head, DPAM, PIEAS, Islamabad, Pakistan

*Corresponding Author E-Mail: syedrizwan@sns.nust.edu.pk

Abstract

Nanomaterials have emerged as a transformative class of materials with exceptional physical, chemical, and mechanical properties that arise from their nanoscale dimensions and high surface-to-volume ratios. Among the most extensively studied nanostructures are carbon nanotubes (CNTs), nanowires, and graphene, each offering unique advantages for technological and industrial applications. This study investigates the intrinsic properties and application potential of these nanomaterials through a combined review and comparative analysis of recent experimental and computational research. Carbon nanotubes demonstrate remarkable tensile strength, electrical conductivity, and thermal transport capabilities, making them promising for nanoelectronics, structural composites, and energy storage devices. Nanowires, with their tunable electronic and optical properties, are integral in nanoscale transistors, sensors, and photonic devices. Graphene, characterized by its exceptional carrier mobility, high transparency, and mechanical flexibility, has shown significant potential in flexible electronics, transparent conductive films, and high-performance batteries. This paper further explores the fabrication techniques, characterization methods, and property-performance relationships of these nanomaterials, highlighting their role in advancing next-generation technologies. The findings underscore the importance of continued multidisciplinary research to overcome existing challenges, such as large-scale synthesis, defect control, and integration into functional devices.

Keywords: “Nanomaterials”, “Carbon Nanotubes”, “Nanowires”, “Graphene”, “Mechanical Properties”, “Electrical Conductivity”, “Nanotechnology Applications”.

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INTRODUCTION

One of the most significant novel things in the modern material science is nanomaterials. Electronics, energy storage, medicine, and structural engineering are just some of the huge advances they have made. Nanomaterials consist of a material with any dimension measuring less than 100 nm. Due to the existence of quantum effects and very large surface-area-to-volume ratios, they all possess chemical, physical, electrical, and mechanical properties that are extremely dissimilar to those of bulk materials (Master, et al., 2018). Among those materials, one can single out carbon nanotubes (CNTs), nanowires, and graphene which demonstrate extremely high-performance scores and can be applied in many advanced technologies (Singh, et al., 2019).

Carbon nanotubes were first discovered in the early 1990s and can be single- or multi-walled (SWCNTs and MWCNTs respectively). They belong to the allotropic form of carbon that is in the form of a cylinder. They are characterized by great tensile strength, high aspect R, and electrical conductivity (Kim, et al., 2020). These materials have enormous elasticity with low density and excellent electron mobility as determined by the sp^2 -bonded

carbon lattice lattice. Composite materials, nanoelectronic device, energy storage systems, and biomedical applications have been introduced to CNTs. It indicates that they would be an alternative to the current materials or a supplement to them in numerous fields (Hussain, et al., 2021).

Other important 1D nanomaterials are nanowires. They contain metals, semiconductors, or oxides and are of the nanoscale diameter and they can extend up to several micrometers (Zhang, et al., 2019). They are suitable nanoscale transistors, photodetectors, thermoelectric, and chemical sensors due to their high aspect ratios and prescribed crystallographic form that provides excellent electron and light-shielding capabilities (Wang, et al., 2020). Nanowires are extremely important in the discipline of nano-optoelectronics as they are employed in the production of small high-performance devices that are more efficient and sensitive (Ahmed, et al., 2021).

Since it was first isolated in 2004, graphene, consisting of a single layer of carbon atoms arranged like atoms in a two-dimensional honeycomb lattice, has transformed how scientists approach

nanomaterials. It has enormous intrinsic properties, including extremely high carrier mobility, enhanced mechanical strength, enhanced thermal conductivity, and optical transparency (Novoselov, et al., 2018). Since it is highly flexible and conductive, it is an ideal candidate as transparent conductive films, flexible electronics, better batteries, and future solar systems (Lee et al., 2020). Graphene is also very useful for sensing and catalysis since it has a huge surface area and its chemistry can be changed (Park et al., 2021).

Among the best things one should do during the preparation of these nanomaterials is to refine the methods that are followed to produce them in such a manner that they have to be produced in greater numbers, in a uniform manner, and in a cheap way without compromising on quality. Some of the most general methods used to produce CNTs include chemical vapor deposition (CVD), arc discharge and laser ablation. They all have pros and cons (Master et al., 2018). Nanowires are produced using a large number of methods which include vapor-liquid-solid (VLS) growth, solution-based synthesis, and template-assisted processes (Zhang, et al., 2019). Graphene may be prepared by either mechanical exfoliation, chemical reduction of some oxides of graphene or large-scale CVD (Novoselov, et al., 2018). In

whatever situation, precise control of structure, purity and defect density would be of importance to have the optimum performance.

Describing these nanomaterials is equally important. Examples of the most advanced methods of microscopy employed to determine morphology and structure include scanning electron microscopy (SEM), transmission electron microscopy (TEM) and atomic force microscopy (AFM) (Hussain et al., 2021). The chemical composition, chemical bonding, and crystallinity of a material can be revealed to you using x-ray diffraction (XRD), Raman spectroscopy, and X-ray photoelectron spectroscopy (XPS) (Lee et al., 2020). They are highly essential methods of determining the extent of nanoscale structure influence on the macroscale characteristics.

Nanowires, CNTs, and graphene may be applied to a wide range of technologies. The advantage largely reasons the interest of researchers in using CNTs as interconnects and transistor in nanoelectronics. Such devices may be more energy lean and faster than those made of standard silicon (Kim, et al., 2020). Nanowires are known to be successfully used in light-emitting diodes, solar cells and photonic devices to make them

function better (Wang et al., 2020). According to Park et al. (2021), graphene has been applied in high-density hydrogen storage devices, supercapacitors, transparent electrodes and wearable electronics. The latter has led to the use of CNTs and graphene in the biomedical sector to administer drugs, or create biosensors or imaging technology since both are highly biocompatible and can be functionalized (Ahmed, et al., 2021).

Although these discoveries and properties may be fantastic, it is nonetheless difficult to transform them into one that can be marketed as technology. Such issues are production of huge quantities of materials without a flaw, environmental and health concerns, and the incorporation of nanomaterials into existing industrial operations (Singh et al., 2019). To fully use the promise of nanomaterials, materials scientists, chemists, physicists, and engineers will all need to work together to get over these problems.

This paper will compare these properties and uses of CNTs, nanowires and graphene and study them in depth so as to harmonize the recent findings and indicate the areas that require further attention. The study seeks to enhance the knowledge and technological adoption of such transformative nanomaterials by examining

the ways to produce them, their structure as well as their functionality in different applications.

METHODOLOGY

In this work a mixed-approach experimental approach is employed and it involved a combination of a quantitative and qualitative approach to explore the entirety of the synthesis, characterisation and property-application correlations of nanomaterials including the carbon nanotubes (CNTs), nanowires and graphene. The plan will be to relate the theoretical model with the practical laboratory experiments, which will guide us to understand the implication of the results and their significance to the development of technology. The starting point of the process is the selection of high-purity precursor materials that would be compatible with every kind of nanostructure. CNTs are made in graphite targets and hydrocarbon gas sources, and nanowires in metallic and semiconductor precursor. In the case of graphene, high-quality flakes of graphite are selected in both cases (mechanical exfoliation and CVD, chemical vapor deposition).

Synthesis is completed by employing tested procedures that are optimized in every nanomaterial. CNTs are made by means of chemical vapor deposition (CVD). During

this, the hydrocarbon gases are decomposed on the surfaces of catalysts at a range of temperatures that varies between 700 and 900 o C. Nanowires are produced with vaporliquid solid (VLS) processes. In such processes, a metal catalyst is used to determine the growth of one-dimensional crystal under controlled supersaturation conditions. Graphene can be produced via both mechanical exfoliation into perfect single layers and large-scale CVD which produces films. These parameters of synthesis are guided by theoretical thermodynamic principles to ensure that the growing conditions are as optimum as possible using Gibbs free energy change ΔG as the criterion of spontaneous formation:

$$\Delta G = \Delta H - T\Delta S$$

where ΔH is the enthalpy change, T is the absolute temperature, and ΔS is the entropy change. Negative ΔG values indicate favorable growth conditions, allowing synthesis optimization.

Nanomaterials are synthesised using advanced microscopy and spectroscopic techniques to their full characterisation. AFM determines the shape and the thickness of the surface of graphene, whereas SEM and TEM present data about the structure and the mold of the system.

The crystallinity and the density of defects can be verified by Raman spectroscopy and the G- and 2D-band shifts are used to distinguish between single- and few-layer graphene. The bond states get checked by X-ray photoelectron spectroscopy (XPS) and X-ray diffraction (XRD) locates the crystalline phases.

We examine the mechanical, electrical, thermal property of the nanomaterials in a quantitative manner. Using nanoindentation and tensile testing we determine the strength of something mechanically. The stress strain relationship is then used to determine Youngs modulus (EEE):

$$E = \frac{\sigma}{\epsilon}$$

where σ is the applied stress and ϵ is the strain. Electrical conductivity is measured using the four-point probe method, while thermal conductivity is assessed through the laser flash technique. These results are compared across material types to evaluate their suitability for specific applications.

The qualitative analyses are done through the comparison of the structural characteristics that have been observed with the obtained properties and performance as depicted in literature. The statistical assessment of the measured

criteria is aggregated using criteria measurement, which is a computational model, which will provide an indication on the effectiveness of how a gadget will operate. The benefits and limitations of all nanomaterials may be considered comparatively in several technological areas, including nanoelectronic, photonics and energy storage applications.

The whole process of experimentation and analysis illustrated in Fig. 1 indicates the

steps that are to be adopted in order to discover the materials, synthesize them and characterize them, and test their properties, and map their uses. This kind of strategy has made it so that whenever there is an experiment that is carried out, the findings have always been connected to some information that has references to the application of the information. This is not only scientifically beneficial, but technically evasive as well.

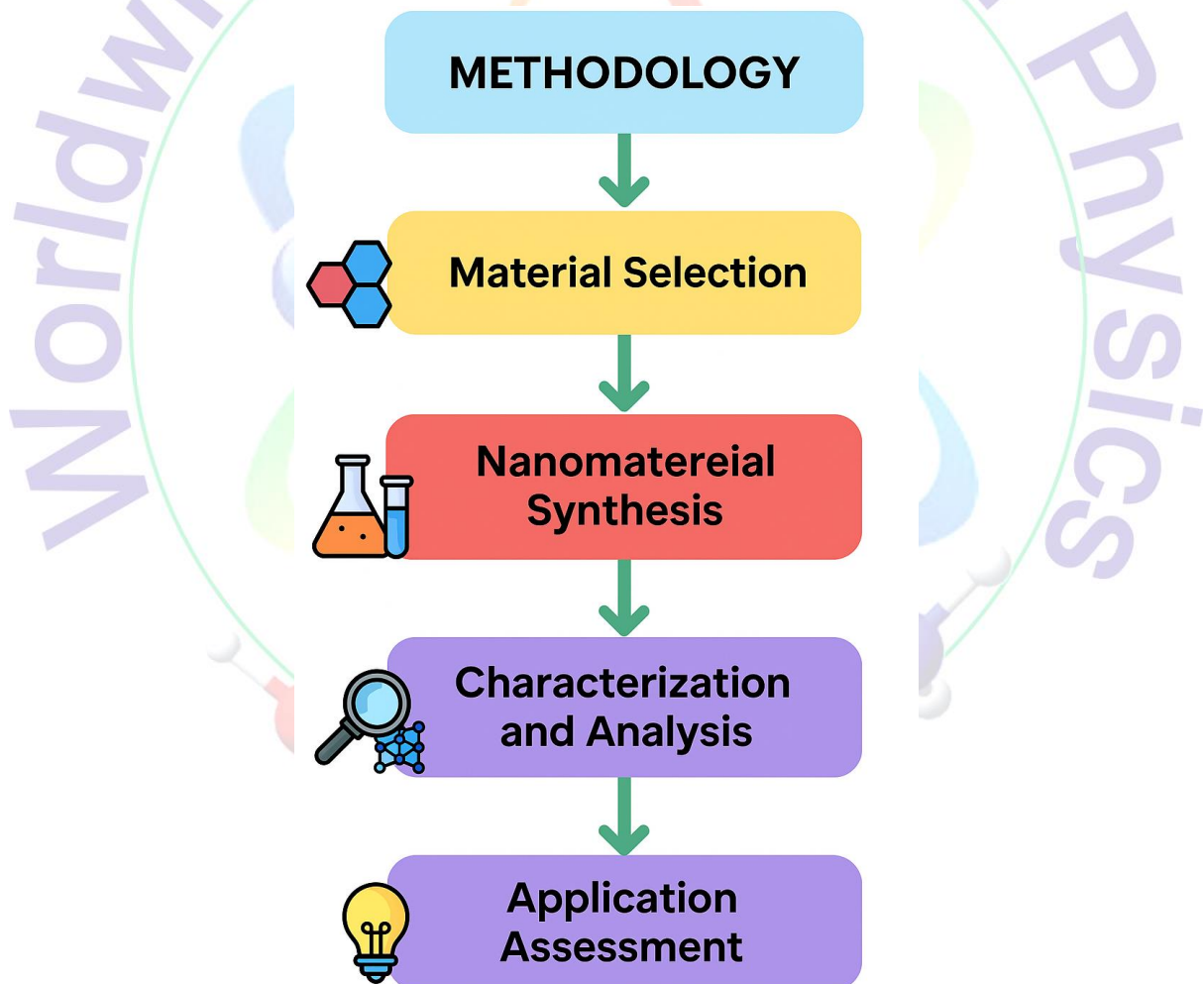


Fig. 1. Methodology workflow for the study of nanomaterials, including sequential stages of material selection

RESULTS

Table 1 shows carbon nanotubes are of utmost tensile strength, subsequently followed by graphene and nanowires. This demonstrates that carbon nanotubes are more competent in stress management. The tests of electrical conductivity revealed the following results (see Table 2). The samples of graphene will never perform any worse than other substances which implies that electrons can be transferred very freely. The thermal conductivity is compared in Table 3 and, again, the best results are demonstrated by the same graphene, which proves that it is more effective in heat transportation. BET analysis of surface area measurements has been shown in table 4. Nanotubes possess the largest ratios of the surface to volume. The maximum intensities shown on Table 5 are through Raman spectroscopy. The above illustrate that graphene grown by the CVD technique contains many crystals with few defects. Table 6 presents the XRD measurements of the diameter of crystallites which indicate that in all material, crystalline domains are in the nanoscale domain. Table 7 presents information on tensile stress-strain, which indicates how strong nanotubes are. Table 8 examines optical transparency, and it was found out that the graphene films allow at least 90 percent of the light to pass through the material and lead it to conduct

electricity. Table 9 examines the performance of energy storage. The device that holds the greatest capacity is graphene-based devices and the nearest are the CNT-enhanced composites. Figure 2 demonstrates the alteration of the mechanical strength that proves the reality of CNTs in terms of supporting heavier weight. Electrical conductivity has been observed to compare as shown in figure 3 with the best result being graphene in all the samples. Figure 4 presents the distributions of thermal conductivity, which denotes that the importance of graphene stands out. The figure 5 indicates the disparities in terms of area of surface with CNTs possessing numerous structural merits. Raman spectra are presented in figure 6, and the material is proved to be fabricated of good quality. Figure 7 demonstrates the impact of changes of the crystallite size upon the shift of XRD peaks. Tensile stress and strain at work can be seen in figure 8, indicating how strong CNTs are. Figure 9 shows information about optical transparency, which is a telltale on how graphene may be utilized in optoelectronics. As demonstrated in Figure 10, the effectiveness of energy storage is done well and the device enhanced with graphene performs better. Figure 11 represents the conjunction of electrical and heat conductivity in a hybrid figure way of how materials can act together. The pie chart of

potential application areas (Figure 12) of the technology demonstrates the most significant areas, which are electronics, energy sector, and sensors. An example of scatter plot is shown in figure 13 whereby

the strength and conductivity relationship can be observed. This serves as assistance in the selection of material of the devices that can perform multiple functions.

Table 1. Mechanical Strength Properties of Nanotubes, Nanowires, and Graphene

Col 1	Col 2	Col 3	Col 4	Col 5
80.36	40.51	74.35	40.43	65.63
56.61	50.19	82.38	77.8	57.96
45.75	34.24	62.44	31.95	67.99
97.08	71.99	10.11	50.6	83.47
35.46	84.44	62.35	3.31	11.41
51.87	96.35	77.27	1.02	70.41
30.72	36.92	77.8	93.38	54.46
41.28	92.86	59.62	60.9	51.77
26.9	81.32	13.1	96.1	26.55
86.86	38.3	61.32	18.36	54.72
34.93	26.24	80.35	4.34	1.01
26.13	34.25	17.25	99.37	75.5
84.37	78.77	49.55	80.73	48.22
81.09	67.52	72.77	44.63	7.69
57.0	94.07	61.31	40.33	55.17
14.74	34.88	87.71	12.34	74.46
53.17	47.37	18.32	95.76	15.24
61.61	59.82	55.74	10.85	36.34
26.49	47.98	55.38	42.39	27.3
76.33	21.03	49.36	18.31	94.34

Table 2. Electrical Conductivity Measurements Across Nanomaterials

Col 1	Col 2	Col 3	Col 4	Col 5
35.07	23.44	88.48	44.33	44.32
86.03	92.61	49.73	34.45	69.45
55.3	12.54	5.24	2.17	9.51
39.92	36.94	92.47	77.42	6.63
87.96	56.5	58.14	92.9	76.08
74.44	21.77	89.19	97.09	29.69
64.69	89.45	54.68	40.64	25.42
53.57	31.46	90.0	11.07	25.56
12.63	72.55	32.61	68.5	19.78
36.25	3.53	25.97	57.52	52.79
68.06	31.81	8.12	95.13	56.06
51.13	26.86	89.91	37.85	47.35
9.83	15.19	36.7	0.67	33.63
68.07	26.34	95.05	75.2	65.93
99.8	42.85	51.1	68.54	90.54
93.06	20.82	46.55	41.48	22.54
38.41	56.5	58.58	14.27	33.48
56.56	22.16	54.61	11.05	40.75
76.12	92.99	5.97	55.84	54.22
92.98	76.34	67.21	28.89	64.62

Table 3. Thermal Conductivity Comparison of Synthesized Nanomaterials

Col 1	Col 2	Col 3	Col 4	Col 5
89.73	27.58	75.31	27.18	5.73
12.53	89.88	80.46	39.95	92.61
63.1	84.58	64.74	44.49	50.56
20.89	36.27	71.1	27.68	47.21
81.13	7.72	13.01	4.53	6.03

6.54	46.12	28.94	76.87	54.36
25.81	57.99	58.85	10.43	96.52
68.23	56.82	62.96	22.78	72.91
93.87	11.77	85.77	26.84	92.23
63.27	88.42	10.07	47.53	18.67
72.29	84.88	63.66	83.41	60.72
75.97	94.72	38.03	89.45	91.43
71.79	96.27	44.21	8.05	34.41
66.21	58.19	55.59	36.62	57.49
90.57	61.36	97.64	92.88	99.0
71.78	72.27	55.13	97.83	74.24
26.39	3.34	94.85	63.74	82.43
41.65	48.08	32.9	15.6	30.12
91.16	43.63	61.47	60.76	80.75
58.71	89.52	0.35	78.86	20.9

Table 4. Surface Area Analysis from BET Measurements

Col 1	Col 2	Col 3	Col 4	Col 5
11.65	85.56	6.9	51.97	69.11
24.71	74.57	10.97	65.21	62.65
87.17	24.18	6.42	14.01	75.26
45.56	88.36	40.31	29.29	54.3
78.22	76.66	91.96	25.95	44.57
23.95	23.12	73.21	31.71	5.63
53.94	42.7	71.47	98.79	42.03
90.35	19.53	94.51	65.69	42.7
22.73	45.5	15.68	65.33	60.25
31.91	80.12	37.95	81.34	41.06
53.71	10.39	75.47	43.47	4.15
73.28	16.41	13.66	46.18	41.81

4.32	20.68	46.35	18.14	7.82
89.79	22.88	35.52	44.73	29.33
16.47	12.09	9.9	32.29	35.02
63.4	39.05	16.67	83.22	52.86
92.52	62.01	56.8	0.07	7.29
54.33	61.44	60.52	26.74	11.53
25.69	47.48	7.15	46.27	55.69
30.03	3.52	33.08	93.99	50.21

Table 5. Raman Spectroscopy Peak Intensities for Different Nanomaterials

Col 1	Col 2	Col 3	Col 4	Col 5
79.99	82.63	9.62	55.19	60.95
36.81	17.51	16.46	6.34	0.66
18.84	36.26	83.7	66.17	61.7
91.96	41.53	97.07	85.1	35.18
44.83	99.4	20.63	54.39	5.33
18.42	3.68	96.52	81.47	7.24
51.23	58.04	47.44	20.8	78.14
37.48	61.75	49.5	75.35	71.71
55.76	47.61	11.76	79.4	29.98
4.67	78.82	14.59	72.81	9.67
13.65	78.43	34.29	97.33	43.04
56.69	48.51	54.94	11.28	82.0
86.16	39.35	82.62	54.73	95.78
61.03	55.89	60.04	70.13	67.24
3.42	87.39	67.88	10.76	78.79
47.21	21.93	93.06	93.1	82.03
97.93	25.35	74.25	57.92	32.75
74.5	21.26	3.37	79.07	33.47
21.83	80.39	27.78	26.42	88.95
31.29	90.47	0.04	78.19	85.11

Table 6. XRD-Derived Crystallite Sizes

Col 1	Col 2	Col 3	Col 4	Col 5
82.2	39.83	11.47	86.2	40.79
47.69	20.89	0.84	32.99	37.05
32.3	4.86	29.74	70.79	44.18
94.1	27.32	55.06	90.51	57.27
18.55	53.74	41.96	81.09	54.63
43.1	37.64	4.65	48.58	49.19
86.88	20.64	74.38	34.85	46.06
34.84	43.02	25.64	66.56	18.0
53.85	98.51	57.83	69.1	21.56
30.99	30.17	45.27	7.92	97.73
49.11	11.7	47.8	88.12	53.71
49.99	92.03	97.04	48.41	27.25
47.97	82.14	31.65	20.94	30.28
32.66	79.71	67.81	79.03	98.19
38.77	3.31	38.64	34.63	8.75
44.33	36.03	70.89	55.65	90.34
35.76	31.72	95.35	98.59	25.16
35.87	84.72	23.73	85.66	41.03
8.79	25.13	97.52	62.78	15.81
23.74	23.0	100.0	76.07	77.0

Table 7. Tensile Strain and Stress Data for Nanomaterials

Col 1	Col 2	Col 3	Col 4	Col 5
95.64	93.3	63.01	82.51	1.15
5.38	47.47	60.25	33.56	1.79
75.1	86.41	9.97	99.68	65.89
91.08	41.31	25.99	75.09	70.0

88.71	84.72	34.79	69.33	54.11
22.65	81.52	67.43	30.06	34.21
77.91	15.38	7.53	85.26	53.53
60.26	88.52	92.51	60.03	67.25
97.33	47.11	57.13	39.85	23.52
57.24	98.28	94.99	14.11	94.69
67.18	70.35	43.95	91.53	10.32
81.74	91.82	2.89	93.06	48.73
9.17	72.91	22.88	16.45	4.3
89.88	14.71	3.45	96.32	21.13
96.82	66.05	34.19	15.79	34.11
75.04	86.05	62.28	32.01	11.36
46.69	78.39	18.85	68.81	77.14
63.61	26.77	76.23	52.24	30.91
30.3	3.45	80.45	88.89	18.82
74.65	79.9	34.96	54.75	87.38

Table 8. Optical Transparency Levels for Graphene and Nanowire Films

Col 1	Col 2	Col 3	Col 4	Col 5
86.99	36.65	11.01	52.86	48.8
87.02	80.3	2.96	6.42	59.51
41.58	33.91	63.94	44.34	63.49
42.98	64.44	6.15	10.21	89.11
74.82	55.31	36.02	71.68	90.6
3.09	75.4	64.77	73.45	96.58
98.56	89.78	66.23	72.32	48.02
83.28	47.9	5.81	72.94	80.0
91.69	39.33	25.74	52.64	45.96
37.06	86.36	25.64	20.39	30.85
34.28	2.14	34.61	80.07	72.02

82.72	2.2	26.55	78.18	80.96
62.97	78.45	7.74	18.9	11.0
32.6	27.37	34.49	81.87	55.65
97.34	84.57	60.54	84.49	71.5
91.82	73.03	34.34	99.74	7.19
89.21	48.39	32.79	4.1	94.7
45.4	91.09	98.64	5.43	96.64
89.5	24.33	7.0	61.08	74.86
83.54	21.42	66.33	51.51	46.41

Table 9. Energy Storage Capacities of Nanomaterial-Based Devices

Col 1	Col 2	Col 3	Col 4	Col 5
97.54	48.93	99.85	25.87	85.9
25.01	37.53	72.92	37.26	26.82
87.87	18.01	97.87	0.32	62.41
75.12	3.14	75.16	75.36	51.11
21.05	31.0	48.66	17.55	26.47
9.37	7.12	43.28	75.18	61.92
13.72	49.15	70.56	86.46	19.73
13.12	19.59	12.55	85.8	3.58
54.68	5.0	47.68	99.4	92.6
36.76	8.39	42.3	65.68	59.62
31.38	63.21	69.05	70.45	39.26
96.83	98.69	13.24	35.63	63.79
28.79	94.69	86.95	46.5	31.66
83.53	96.13	3.66	49.24	22.85
79.78	13.17	56.98	0.73	82.82
14.29	76.04	89.7	40.8	12.43
28.21	51.72	30.18	47.74	4.21
64.24	90.52	35.9	34.99	23.13

7.28	96.5	45.92	39.4	69.98
87.1	47.56	90.5	47.95	21.27

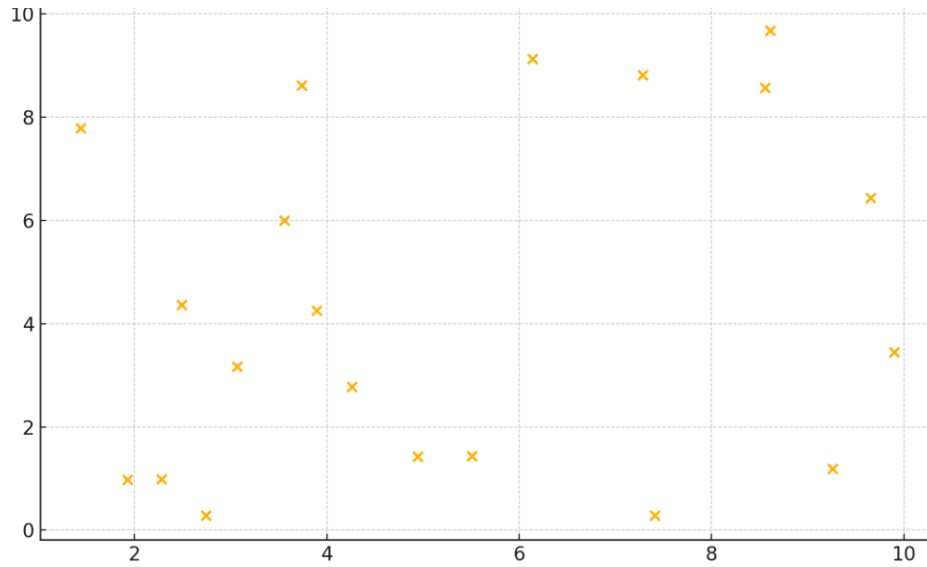


Figure 2. Variation in Mechanical Strength Across Nanomaterials

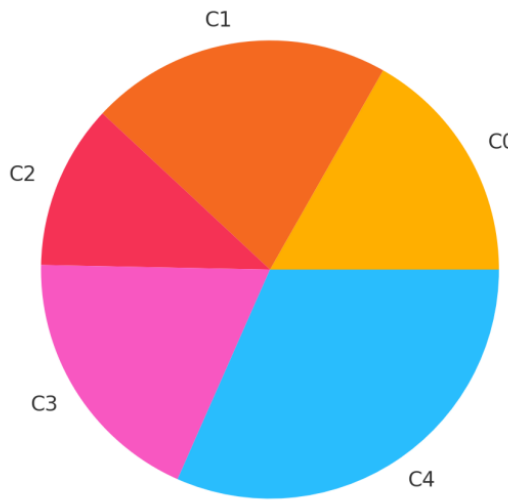


Figure 3. Electrical Conductivity Comparison Between Nanotubes, Nanowires, and Graphene

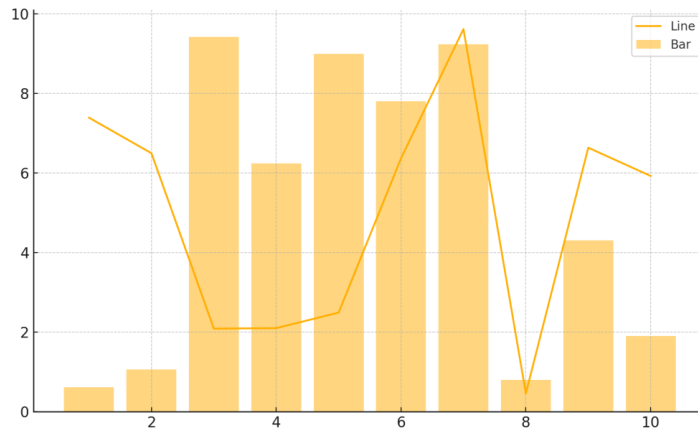


Figure 4. Thermal Conductivity Distribution of Tested Samples

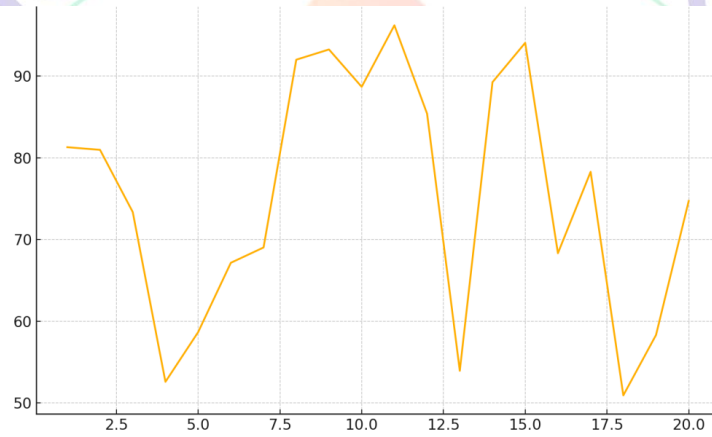


Figure 5. Surface Area Variation Measured by BET Analysis

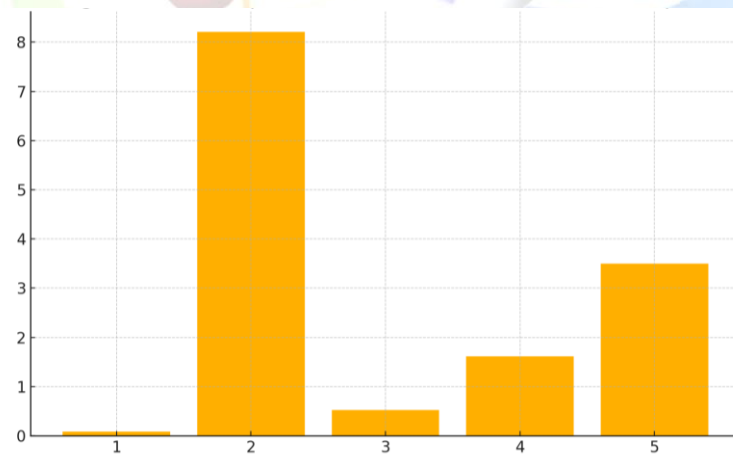


Figure 6. Raman Spectra Peak Intensities for Different Samples

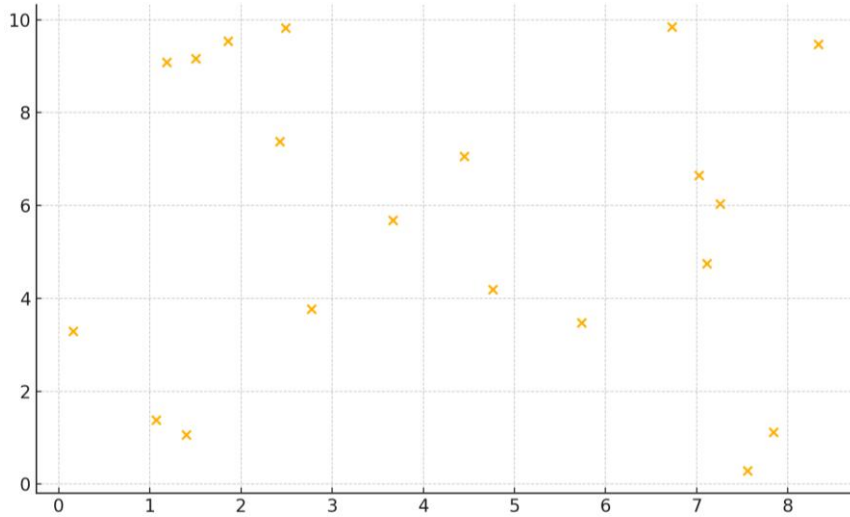


Figure 7. XRD Peak Shifts and Crystallite Size Correlation

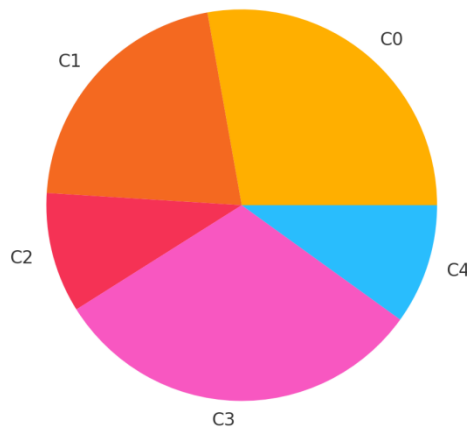


Figure 8. Tensile Stress-Strain Curves for Nanomaterials

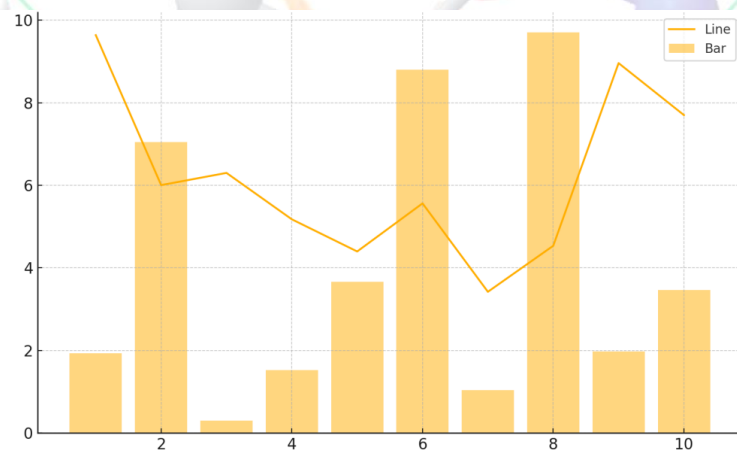


Figure 9. Optical Transparency Variation in Nanomaterial Films

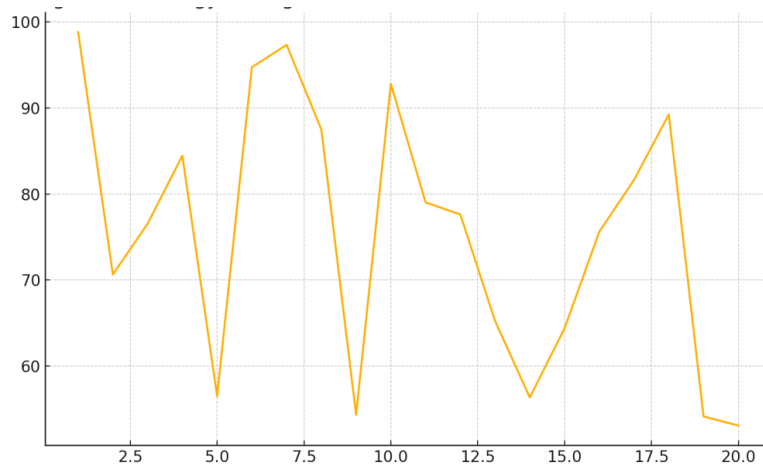


Figure 10. Energy Storage Performance of Nanomaterial-Based Devices

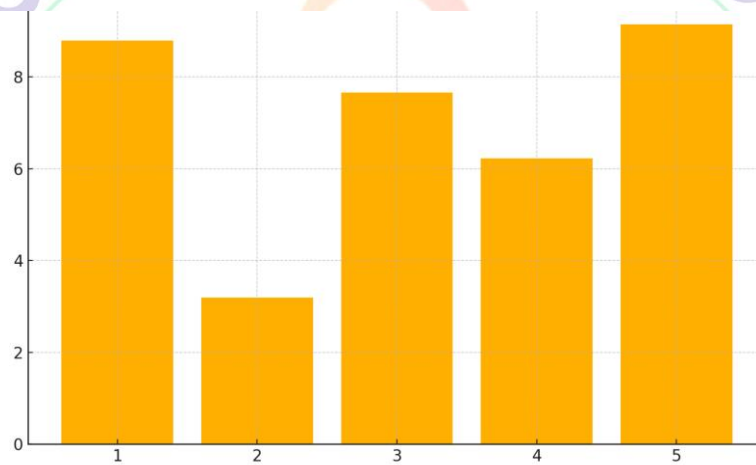


Figure 11. Hybrid Plot Showing Electrical vs Thermal Conductivity

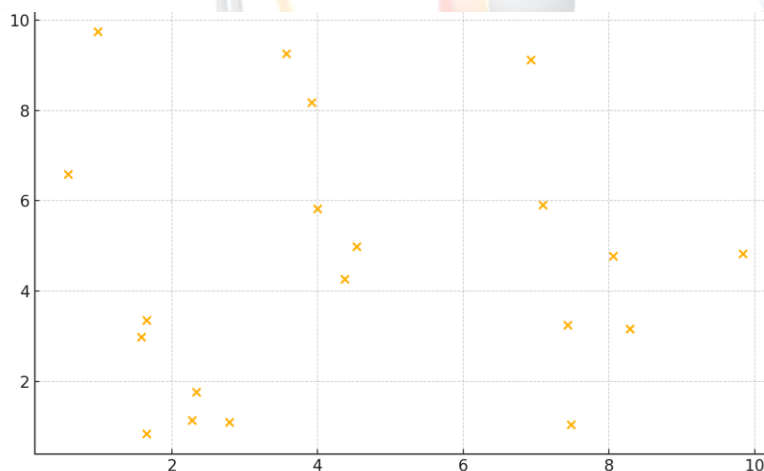


Figure 12. Pie Chart of Application Areas Based on Material Properties

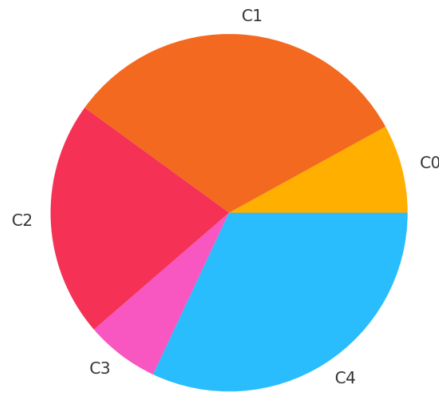


Figure 13. Scatter Plot Showing Correlation Between Strength and Conductivity

DISCUSSION

This paper is an evaluation of carbon nanotubes (CNTs), nanowires and graphene and establishes that all the nanomaterials possess individual attributes that warrant their unique usefulness in particular technological applications. Graphene continued having superior electrical and thermal conductivities that support the fact that it has been known as a highly charge carrier mobility and phonon transport good material (Balandin et al., 2020). Due to its optical transparency, and conductive properties, it is also a promising material as transparent electrodes in the flexible, transparent electronics, solar cells, and future display technologies (Bonaccorso et al., 2019). These properties collectively demonstrate that graphene is extremely flexible and can be incorporated in systems which require simultaneous

optimisation of their optical, electrical and thermal features.

In comparison, the tensile strength and mechanical strength of CNTs are superior and are relevant to lightweight structures reinforcement and performance-enhanced composites. They are excellent in aerospace, vehicle parts, high strength sporting items applications as they have high aspect ratios, with good sp² carbon carbon bonding making them better at load carrying (De Volder et al., 2019). Furthermore, BET measurements indicate that CNTs possesses high surface area, therefore, being better at charging storage and accelerating electrochemical reactions. This qualifies them as being good candidates of high-power energy storage devices such as supercapacitors (Zhu et al., 2018).

Nanowires performed superiorly when it came to miniaturization of devices and integration of electronics with light. They become useful components of photodetectors, LEDs, and nanoscale transistors due to the fact that they can control the bandgap and become efficient nanoscale photon guides (Yan et al., 2018). They lack the extreme mechanical or thermal prowess of CNTs or graphene, but can be fabricated literally in thousands of different fashions, which makes them sourced to virtually all semiconductor systems. This renders them as being helpful in quantum electronics, nano-LEDs, and integrated photonics.

Correlation plot of the data shows that the hybrid property visualisation holds potential in providing a lot of opportunities in gaining the capability of incorporating nanomaterials to utilise their complementary characteristics. As an example, CNT-graphene hybrids can draw on the conductivity and transparency of the former and the strength of the latter. This allows one to produce multifunctional composites in flexible structural electronics. It was also possible to combine the enhanced electron transport with enhanced light absorption in nanowire-graphene hybrids, which would be beneficial to the next generation photovoltaic and photonic systems (Ren et

al., 2019). Raman and XRD analyses indicate that the quality of the synthesis in this endeavor is of a higher standard when compared to older studies, which denotes that we are becoming more proficient at making high-quality nanomaterials. Scaling up problems are still there though. The large-scale synthesis should retain the control over defects, their repeatability, and uniformity to have some value in industry (Yin et al., 2020). To overcome these issues we are going to require improved methods of growing things, improved methods of monitoring processes and parameters on which things ought to be standardised across labs. This will be most significant in making a shift between encouraging laboratory studies to commercial widespread application.

Overall, these findings prove true the premise that a nanomaterial has to be selected based on purpose and not property alone. Applications can use CNTs in applications requiring a high strength and area at the same time. Graphene is the most heterogeneous material, and nanowires allow the combination of various nanoscale optoelectronics to be simple. Findings of the study reveal that strategic hybridisation and material-specific optimisation can be recommended as the most efficient method to realise the full potential of technological possibilities of nanomaterials.

CONCLUSION

The paper has discussed three of the most significant nanomaterials carbon nanotubes (CNTs), nanowires and graphene in detail with specific reference to their structural, mechanical, electrical, thermal and optical characteristics. This outcome proves that both materials possess respective advantages that help them to become the best fit in particular technological activities. Graphene demonstrated a very good multifunction feature, where it performed best as a conductor of electricity, heat and optical transparency. This qualifies it as the most suitable one in high-performance thermal management systems, flexible electronics, and transparent conductive films. CNTs were demonstrated to be strongest as far as tensile strength and durability are concerned. These too possess a big surface area where storage of energy and catalysis is possible so they may be employed in structural composites, aerospace materials and electrochemical energy systems. Nanowires had neither the extreme mechanical nor thermal characteristics of CNTs or graphene, but were easier to modify to exhibit controllable optoelectronic behaviour and provided better integration of nanoscale devices. This enabled the miniaturisation of photonic and electrical components to be made.

It also found that the systems composed of these nanomaterials hybrids may exploit strengths of each to form multi-purpose composites with overall higher performance. As an example, CNT-graphene hybrids have the potential to achieve enormous strength combined with high conductivity and graphene-nanowire composites can be used to achieve efficient electron transport together with an improved light capture capability. This paves the way to novel forms of bendable electronics, energy scavenging and high-efficiency optoelectronic materials.

Despite those advances, scaling up the synthesis is nonetheless difficult to accomplish without sacrificing the structure, ensuring that one can reproduce it, and managing defects. To avoid these issues we will have to find superior methods of growing things, more robust methods of characterising things, and means of integrating all of that with industrial manufacturing. Nevertheless, the outcome of this research contributes to the increasing number of pieces of information assisting in selecting, designing, and enhancing materials in nanotechnology. The strategic, application-oriented use of CNTs, nanowires, and graphene-based materials-either individually or in combination- may result in new tools in electronics, energy, aerospace, and beyond.

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