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Engineering performance through geometry: A comparative analysis of swcnts vs. Mwcnts

Som Sengupta
Class XII, Jamnabai Narsee, Mumbai

Abstract

Single-walled and multi-walled carbon nanotubes (SWCNTs and MWCNTs) represent distinct forms of carbon nanostructures whose geometric differences have profound implications on their properties and engineering performance. This paper provides a comprehensive comparative analysis of SWCNTs versus MWCNTs, emphasizing how structural dissimilarities impact their applications in electronics, composite materials, energy storage and thermal management. We review recent findings (2020–2025) from high-quality literature to elucidate differences in diameter, wall structure, electrical/thermal conductivities, mechanical strength and processing.

SWCNTs consist of a single graphene cylinder with diameters ~1–2 nm, whereas MWCNTs comprise multiple concentric graphene cylinders with outer diameters up to tens of nanometers. These geometric distinctions lead to different performance outcomes. For example, SWCNTs can exhibit exceptional electrical conductivity or semiconducting behavior (depending on chirality) and ultra-high flexibility, making them ideal for nanoscale electronics, sensors and flexible devices. In contrast, the robust multi-layer structure of MWCNTs lends them higher bulk thermal stability and ease of bulk production, favouring their use in structural composites, bulk conductive additives and thermal interfaces. We include figures illustrating the structural differences and tabulated comparisons of key properties and use-cases.

Application-driven discussions demonstrate that the choice between SWCNTs and MWCNTs is often a trade-off between performance and practicality. While SWCNTs offer superior properties per unit and more predictable behavior at the nanoscale, MWCNTs are more readily available at scale and cost-effective for many industrial uses. The paper concludes that SWCNTs and MWCNTs offer complementary strengths. SWCNTs deliver exceptional properties for high-performance electronics, sensors, and thermal systems, while MWCNTs provide robustness, scalability, and cost-efficiency suited for composites, energy storage, and structural applications. As fabrication and integration methods improve, hybrid systems using both forms are likely to emerge. The future of CNTs lies not in choosing one over the other, but in combining their advantages to unlock new possibilities across engineering and industrial domains.

Introduction

Carbon nanotubes (CNTs) are cylindrical one-dimensional carbon allotropes renowned for their exceptional mechanical strength, electrical conductivity and thermal properties. Since their discovery in the early 1990s, CNTs have been intensively studied for a wide range of engineering and industrial applications. Two broad classes of CNTs are recognized. Single-walled carbon nanotubes (SWCNTs) and Multi-walled carbon nanotubes (MWCNTs).

A SWCNT consists of a single graphene sheet rolled into a seamless hollow cylinder, typically with a diameter in the order of a nanometer. In contrast, a MWCNT comprises several concentric graphene cylinders (like a "Russian doll" structure), with an overall diameter ranging from a few nanometers up to tens of nanometers depending on the number of walls[1]. These structural differences are illustrated in Figure 1.

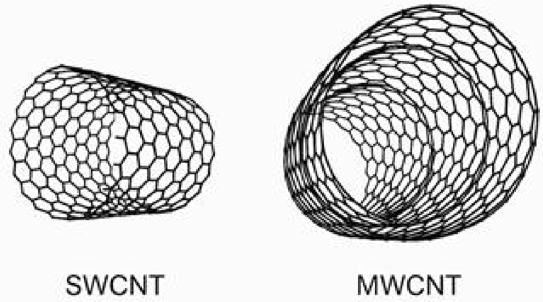


Figure 1: Structural differences between SWCNT and MWCNT

The geometry of CNTs, specifically the number of walls and resulting diameter and surface characteristics, fundamentally influences their material properties and thus their performance in engineering applications. For instance, all carbon atoms in a SWCNT are exposed on its surface, whereas in a MWCNT only the outermost wall is directly exposed, with inner walls shielded within the structure[2]. This difference affects how each type of nanotube interacts with its environment (e.g. with matrix materials in a composite or with electrolyte in a battery) and how easily they can be chemically functionalized. Likewise, the presence of multiple walls in MWCNTs can enhance certain properties like overall rigidity and resistance to buckling but can also introduce more complexity in electron transport (due to interwall interactions) and make precise characterization more challenging.

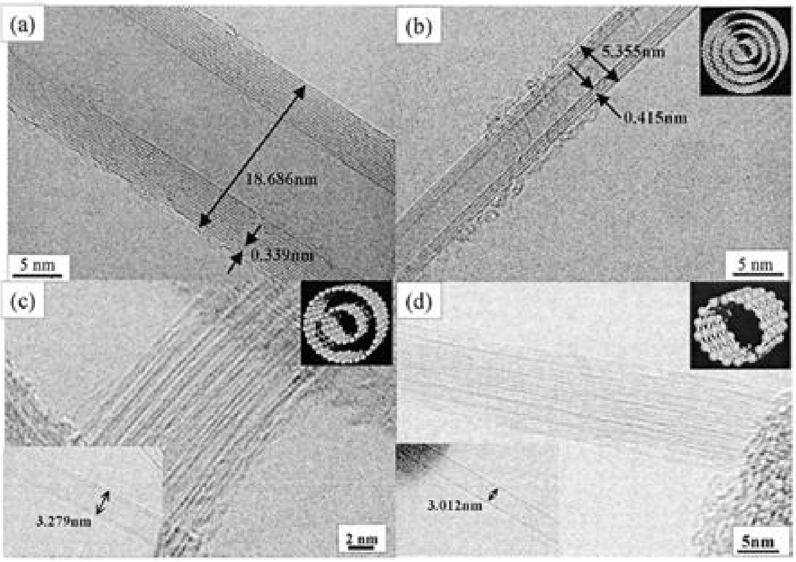
This paper provides an in-depth comparative analysis of SWCNTs versus MWCNTs, with an emphasis on how their structural and geometric differences translate to performance differences in practical applications.

Structural Differences and Intrinsic Properties of SWCNTs vs. MWCNTs

A) Geometry and Structure

SWCNTs are essentially graphene sheets rolled into a cylinder with a single atomic layer wall. They typically have diameters on the order of 0.5 – 2 nm (often ~1 nm on average) and can be many microns in length. Each SWCNT is defined by a chirality (roll-up vector) that determines its atomic arrangement and electronic properties. In contrast, MWCNTs consist of multiple concentric graphene cylinders (like tubes within tubes). A MWCNT can be thought of as several SWCNTs of different diameters nested together. The inter-wall spacing is roughly similar to the spacing between graphene layers in graphite (~0.34 nm).

MWCNT outer diameters typically range from ~2 nm for the thinnest double-walled tubes up to tens of nanometers (even 50–100 nm for those with many walls). Figure 2 shows a transmission electron microscope (TEM) comparison of a thin SWCNT versus a thicker MWCNT, highlighting the stark contrast in wall structure and diameter.



(a) MWCNT, (b) 4 layered CNT, (c) DWCNT bundle, and (d) SWCNT bundle obtained from CCVD method.

The one-atom-thick wall of SWCNTs means that 100% of the carbon atoms are surface atoms. This gives SWCNTs a very high specific surface area and makes their properties extremely sensitive to surface chemistry and defects. MWCNTs, having inner walls, effectively contain a large fraction of “buried” atoms that do not directly contact the environment. One consequence is that pristine SWCNTs and MWCNTs may differ in how they interact with other materials. For example, SWCNTs tend to form ropes or bundles due to van der Waals attraction and all tubes in the bundle are accessible to external contact or functionalization. MWCNTs also agglomerate, but even when dispersed, only the outermost graphene layer is readily available for functionalization or bonding. The inner walls contribute more to the mechanical stiffness than to interfacial interactions. Studies have noted that SWCNTs often have a higher propensity for certain chemical modifications (e.g. oxidation, carboxylation) to introduce functional groups, whereas MWCNTs can be more structurally robust against chemical attack (the outer wall protects inner walls). However, if a defect does form in a MWCNT wall, it may be “locked in” on an inner layer where repair is difficult. SWCNT defects, while more likely to occur during harsh chemical processing, are at least all on the surface where they might be healed or passivated more directly.[3]

Another key structural aspect is chirality (twist of the graphene lattice) in SWCNTs. Chirality does not apply in the same way to MWCNTs, since a MWCNT is a composite of multiple concentric tubes that could each have their own chirality. In a SWCNT, the chirality (defined by integer indices *n*, *m*) dictates whether it behaves as a metal or semiconductor. Armchair SWCNTs (n=m) are metallic, whereas other chiralities can present semiconducting bandgaps of various sizes. This means a batch of SWCNTs is typically a mixture of ~1/3 metallic and ~2/3 semiconducting tubes unless special sorting or selective growth techniques are applied.

By contrast, a MWCNT generally behaves as a metallic conductor, even if some shells are semiconducting, the presence of at least one metallic shell (often the outer shell tends to act metallic due to its larger diameter) provides a conduction pathway. Moreover, inter-shell electronic coupling can cause the overall MWCNT to conduct, effectively averaging out the distinct electronic behaviors of individual walls. Thus, SWCNTs offer tunable electronic properties (via chirality control) ranging from semiconductor to metal, while MWCNTs inherently act more like metallic conductors in most applications.

B) Mechanical Properties

Both SWCNTs and MWCNTs are celebrated for their mechanical strength and stiffness, attributable to the strong sp^2 carbon-carbon bonds in the graphene lattice. However, their mechanical responses differ in subtle ways because of geometry. A perfect isolated SWCNT has a theoretical Young's modulus on the order of 1 TPa (terapascal) and tensile strength around 50–100 GPa. MWCNTs have a similarly high Young's modulus (experimentally measured ~0.8–1.3 TPa) and tensile strength in the range of 10–60 GPa for multi-walled tubes. The lower observed strength of MWCNTs (despite more material in cross-section) is often due to defects and the "sword-in-sheath" failure mechanism. When stretched, the outermost wall of a MWCNT typically breaks first, then slides off the inner walls, which limits the load that the whole nanotube can bear. SWCNTs, being single crystals of carbon, can theoretically achieve higher strength per unit cross-section (with reported values up to ~100 GPa) but are also more susceptible to any defect greatly diminishing that strength.[4]

One notable difference is in flexibility and bending stiffness. An SWCNT, with its minuscule diameter and single-wall structure, is extremely flexible. It can be sharply bent or curved (even tied in knots in some experiments) and still recover, as long as the bend radius is not so small as to introduce a kink defect. The bending stiffness scales with the moment of inertia of the tube's cross-section. A thinner tube (SWCNT) has much lower bending rigidity than a thicker (multi-walled) tube of the same material properties. Thus, MWCNTs are generally stiffer in bending and less flexible than SWCNTs. For example, an SWCNT can buckle elastically under compression or bending at relatively large curvature, whereas a larger-diameter MWCNT will resist bending until a higher force and then potentially fracture rather than elastically deform if its outer walls fail. This difference is reflected in applications. SWCNTs are often preferred in roles requiring flexibility (e.g. flexible electronics or bendable films) whereas MWCNTs, with their higher *effective* stiffness, can contribute more to structural reinforcement in composites. The multiple walls in MWCNTs effectively make them behave like larger-diameter tubes, which are harder to bend.

Defect tolerance is another mechanical aspect. The multi-wall nature of MWCNTs can sometimes allow them to survive defects better. A defect in one wall does not completely sever the structure if adjacent walls remain intact. The inner walls can carry load if an outer wall fails, giving a sort of built-in redundancy. SWCNTs lack this redundancy. A significant defect (like a vacancy or Stone-Wales defect) directly compromises the entire tube's strength. However, because SWCNTs have fewer atoms, they may have fewer initial defects for a given length when synthesized under optimal conditions. Some studies have reported that as-grown SWCNTs can have fewer intrinsic defects than as-grown MWCNTs, leading to higher strength in pristine form.[5] During composite processing or functionalization, though, SWCNTs are more prone to damage due to their all-surface character. MWCNTs' outer layer might chemically react while protecting inner layers, but any introduced defect in inner shells is very hard to repair or heal.

C) Electrical Conductivity

SWCNTs have extraordinary electrical conductivity when they are metallic in character – individual metallic SWCNTs can carry current densities in excess of 10^9 A/cm² with near-ballistic transport over sub-micron lengths. Semiconducting SWCNTs, on the other hand, behave like p-type or n-type semiconductors depending on doping and have been used as the channel material in field-effect transistors (CNT-FETs). The diversity in electronic behavior is a double-edged sword. It enables many applications (including semiconducting electronics), but it also means that pristine SWCNT samples are heterogeneous unless sorted, which is a challenge for consistent device fabrication.

MWCNTs, comprising multiple shells, are typically good conductors (though not quite as conductive as a purely metallic SWCNT). A comparative value often cited is that bulk electrical conductivity of SWCNT mats or fibers can reach ~10^6 S/m, whereas MWCNT aggregates might be on the order of 10^5 S/m. This reflects both the intrinsic conductivity and the contact resistance between tubes.

Chirality control in SWCNTs remains an active area of research. Ideally one would like purely metallic SWCNTs for use as nano-interconnects or transparent conductors, or purely semiconducting SWCNTs for transistor channels. Progress has been made in sorting techniques (e.g. selective chemistry, density gradient ultracentrifugation) and in tailored growth of certain chiralities, but industrial-scale production of chirality-pure SWCNTs is not yet achieved in 2025. Meanwhile, MWCNTs bypass this issue by offering a robust, always-conductive material (though without a semiconducting option). Consequently, for electronics requiring semiconductors, SWCNTs are essential, whereas for applications needing conductivity or EMI shielding, MWCNTs offer a cheaper solution.

Summary of Key Differences

To summarize the intrinsic differences, Table 1 provides a side-by-side comparison of SWCNTs and MWCNTs in terms of structure, typical dimensions and baseline properties. This will serve as a reference for the discussions in subsequent sections.

Feature	SWCNT	MWCNT
Structure	Single graphene cylinder (1 wall)	Multiple concentric graphene cylinders (multiple walls)
Diameter	~0.5–2 nm (usually < 2 nm)	Typically, > 2 nm; can range ~5–50 nm or more for many walls
Length	Up to tens of µm (or mm in aligned growth) – high aspect ratio (often >10,000:1)	Similar order of length (µm), aspect ratio typically 100–1000:1 (depending on diameter)
Production	More challenging; requires catalyst and precise conditions for high-quality growth. Bulk synthesis expensive, fewer manufacturers (scale in hundreds of tons/year scale by 2025)	Easier bulk synthesis (arc discharge, CVD etc.); produced at industrial scale by many companies. Cheaper (order of $100 per kg)
Purity	As-grown material often mixed chirality; separating metallic/semiconducting is needed for some uses. More residual catalysts if grown by CVD (single wall growth yields issues)	As-grown MWCNTs can be obtained in high purity (after removing amorphous carbon). Less chirality concern, generally all conductive. Bulk purity often high (few structural defects per wall)
Electrical Conductivity	Can be extremely high for metallic SWCNT (ballistic transport) – up to ~10^6 S/m in bulk films. Semiconducting SWCNT have tunable bandgaps. Requires mixture control for uniform behavior.	Typically conductive (no significant bandgap overall). Bulk conductivity ~10^5 S/m. Not as high as metallic SWCNT networks, but sufficient for most conductive composite needs. Cannot act as semiconductors (mostly metallic behavior).

Table 1: Comparison of structural features and intrinsic properties of Single-Walled (SWCNT) vs. Multi-Walled Carbon Nanotubes (MWCNT).

Applications

Having established the fundamental differences, we now turn to how these translate into performance in various engineering applications. In each domain, the choice between SWCNT and MWCNT depends on balancing the superior intrinsic properties of SWCNTs versus the practical advantages of MWCNTs (cost, availability, robustness), as well as specific requirements of the application (e.g., need for semiconductor behavior, transparency, mechanical load, etc.).

A) Electronics and Optoelectronics Applications (Simplified Summary)

Carbon nanotubes (CNTs) are increasingly used in electronics and optoelectronics, including in transistors, wires, sensors and transparent films. The structural differences between single-walled (SWCNTs) and multi-walled (MWCNTs) nanotubes strongly influence their specific roles in these technologies.

In transistor and logic device applications, SWCNTs are preferred because many exhibit semiconducting behavior and possess a direct bandgap, enabling them to function similarly to silicon. Between 2020 and 2023, several advances have demonstrated high-performance SWCNT-based transistors with excellent current output and switching speed. MWCNTs, however, usually contain metallic inner walls that interfere with gate control, making them unsuitable for transistor use. As a result, SWCNTs dominate in nano-electronic applications such as field-effect transistors (FETs).

For interconnects and conductive wiring within microchips, both SWCNTs and MWCNTs have been explored as alternatives to copper. MWCNTs are more practical in these settings due to their larger diameter, which enables higher current-carrying capacity and because they are easier to fabricate and connect during manufacturing. Although SWCNTs can achieve extremely high conductivity, they are difficult to purify and align consistently, limiting their reliability in wiring applications.

In transparent conductive films (TCFs), used in technologies such as touchscreens and solar panels, SWCNTs offer significant advantages due to their ultra-thin structure. They combine high electrical conductivity with excellent optical transparency, making them ideal for flexible displays and wearable sensors. In contrast, MWCNTs are bulkier and tend to form light-blocking bundles, reducing transparency and performance in such applications, although they are cheaper and easier to produce.[6]

In sensor technologies, both SWCNTs and MWCNTs are used, but for different reasons. SWCNTs are ideal for high-sensitivity chemical, biological and strain sensors because of their small diameter and high surface area, which allow them to respond to single molecules or slight changes. MWCNTs, while less sensitive and more variable in performance, are widely used in robust, cost-effective sensors, especially in electrochemical applications, due to their ease of processing and lower cost.

In photonics and quantum devices, SWCNTs stand out because their optical properties are well-defined by their chirality and structure. This allows them to emit light at specific wavelengths and be used in fiber lasers, optical sensors and quantum light sources. MWCNTs, lacking a clear bandgap and having more complex, metallic inner walls, do not perform well in these advanced optical applications and are generally not used in this space.

In summary, SWCNTs are favoured in applications requiring precision, transparency, semiconducting behavior, or tuneable optical properties, while MWCNTs are often used in bulk, structural, or cost-sensitive applications where their robustness and ease of use make them more practical.

B) Composite Materials and Mechanical Reinforcement

When carbon nanotubes (CNTs) are added to plastics or rubbers, the aim is to enhance mechanical strength, stiffness, electrical conductivity and sometimes thermal performance. MWCNTs are more commonly used in industrial settings because they are cheaper and available in bulk. SWCNTs, although stronger and more conductive on a per-unit basis, are harder to produce and disperse evenly. Both types can improve properties at low loadings, but SWCNTs generally achieve similar results, especially electrical conductivity, at lower weight percentages due to their high aspect ratio. For example, 0.1% SWCNT can be as effective as 0.5% MWCNT. However, SWCNTs can significantly raise viscosity during mixing and are more prone to bundling, making them difficult to process in large volumes.

In terms of mechanical properties, MWCNTs often provide better toughness due to their multi-layered structure. When stress is applied, the inner tubes can still hold together even if the outer layers are pulled apart, a phenomenon known as the "sword-in-sheath" effect. SWCNTs, if well dispersed, offer excellent reinforcement but are more fragile during harsh processing. Many studies have shown that MWCNT composites, especially when functionalized to improve bonding, significantly improve tensile strength and fracture resistance.

For high-temperature and metal matrix composites, MWCNTs are preferred because they are more robust. Their outer walls can take damage while inner ones remain structurally intact. This makes them more suitable for use in metal or ceramic matrices, where processing involves high temperatures. SWCNTs, on the other hand, can degrade more easily and are challenging to integrate into molten metals. Aluminium reinforced with MWCNT, has shown measurable improvements in strength and wear resistance even at low loadings.

In electrical and EMI shielding applications, both types of CNTs are useful. SWCNTs require smaller amounts to achieve electrical conductivity, making them ideal for ultra-lightweight or low loading applications. However, due to cost constraints, MWCNTs are often used in industrial applications where performance requirements are moderate and cost-effectiveness is key. Some advanced formulations use a blend of both, with MWCNTs providing structural support and SWCNTs enhancing conductivity.[7]

Thermal conductivity in composite materials is another area where CNTs add value. They help in improving heat flow in thermal interface materials, heat spreaders or energy storage systems. MWCNTs are again favoured due to ease of processing and lower cost. While SWCNTs offer higher intrinsic thermal conductivity, they are seldom used in bulk applications because of their fragility and expense. Vertical MWCNT arrays have even been engineered to act as efficient thermal pads, a format where SWCNTs are not suitable due to their mechanical weakness.

In biomedical and flexible electronics applications, SWCNTs often take the lead. Their smaller size allows for better biocompatibility and reduced tissue retention, which is critical for wearable devices and medical implants. Additionally, SWCNTs can absorb near-infrared (NIR) light, making them suitable for photothermal therapies and controlled drug delivery. MWCNTs, unless properly treated, may cause more inflammation and are generally avoided in sensitive healthcare-related applications.[8]

In conclusion, both SWCNTs and MWCNTs offer distinct advantages depending on the application. SWCNTs excel in high-performance, lightweight and biocompatible systems where minimal loading and precision matter, but their high cost and processing challenges limit widespread use. MWCNTs dominate industrial applications thanks to their robustness, cost-effectiveness and ease of integration into composite systems.

C) Energy Storage Applications (Batteries and Supercapacitors)

Carbon nanotubes (CNTs) are widely used in energy storage systems like lithium-ion batteries and supercapacitors because of their high conductivity and large surface area. The performance varies depending on whether single-walled (SWCNTs) or multi-walled (MWCNTs) nanotubes are used.

1. Lithium-Ion Batteries

In lithium-ion batteries, MWCNTs are widely used as conductive additives (typically 1% – 5% by weight) in cathodes such as $LiFePO_4$ or NMC to improve conductivity and rate performance. While

SWCNTs provide even better conductivity at lower loadings, they are expensive and more difficult to mix, often increasing slurry viscosity and forming clumps. MWCNTs, with their more robust structure, handle processing more effectively and integrate more easily. In flexible or stretchable batteries, SWCNT films are preferred due to their high flexibility and excellent conductivity, whereas the stiffer nature of MWCNTs makes them less suitable. As anode materials, both SWCNTs and MWCNTs can store lithium on their surfaces. However, SWCNTs have a higher theoretical capacity and allow better lithium access thanks to their smaller diameter. MWCNTs, though offering slightly lower capacity, are more robust and easier to use in large-scale production. In hybrid anodes, especially silicon-based designs, MWCNTs are commonly used as conductive scaffolds due to their mechanical strength and reliable structure, while SWCNTs can also perform this role effectively but face cost and scalability challenges.

2. Supercapacitors (EDLCs)

Carbon nanotubes (CNTs) are widely used as electrode materials in supercapacitors due to their excellent surface area and conductivity. SWCNTs offer higher accessible surface area and lower internal resistance, which translates to greater specific capacitance and higher power output. However, MWCNTs are easier to compact into dense electrodes, making them more practical for real world devices where volumetric energy density matters. When coated with pseudocapacitive materials like MnO_2, both SWCNTs and MWCNTs show enhanced performance, though MWCNTs often provide a more stable support structure for these coatings. In terms of power handling, SWCNTs typically perform slightly better due to their lower resistance, but both types offer long cycle life, with durability depending more on electrode integration and formulation than on nanotube type.[9]

In summary, SWCNTs offer top-tier performance in energy storage devices – highest conductive network efficiency, potentially higher capacitance utilization. But MWCNTs are the workhorse in commercial and scale-up contexts. As of mid-2020s, most battery and supercapacitor products that contain CNTs are using MWCNT powders (or MWCNT fibers) as additives. For example, electric vehicle battery companies have added MWCNTs to electrode formulations to improve rate capability and longevity. Meanwhile, SWCNTs are seen in cutting-edge prototypes, like a paper in *Nature* (2023) demonstrating a flexible supercapacitor fiber entirely made of SWCNT yarn, achieving remarkable energy density for a fiber device. Something MWCNT yarn might not achieve as well due to lower conductivity or flexibility.

D) Thermal Management Applications

Carbon nanotubes (CNTs) are increasingly used in thermal management for electronics, energy systems and aerospace. In thermal interface materials (TIMs) like greases and pads, both SWCNTs and MWCNTs enhance heat conduction. SWCNTs offer higher thermal conductivity at lower loading, but they are harder to disperse evenly and more costly. MWCNTs are more stable in composites and often chosen for commercial TIMs due to better dispersion and cost-effectiveness. SWCNT films, when well-aligned, can act as ultra-thin heat spreaders with exceptional in-plane thermal conductivity, surpassing MWCNT films in performance. However, such applications remain limited to research due to cost.

In phase change materials (PCMs) used for thermal energy storage, MWCNTs are more practical. They significantly improve the thermal conductivity of materials like paraffin at a reasonable cost and without major processing issues. SWCNTs could perform better but are rarely used at scale for such bulk applications. In nanofluids, where CNTs are dispersed in liquids for heat transfer, SWCNTs show better thermal performance due to higher aspect ratio, but dispersion challenges make MWCNTs more suitable for real-world use.[10]

Although SWCNTs have higher intrinsic thermal conductivity, MWCNTs often perform better in composites, thanks to their multi-wall structure, which provides more continuous pathways for heat.

In high-temperature applications, MWCNTs also show slightly better oxidation resistance as their inner walls survive longer. For controlling thermal expansion in polymers, both types reduce the coefficient of thermal expansion, but MWCNTs are more commonly used due to cost.

In summary, SWCNTs offer higher performance in specialized and lightweight thermal systems, while MWCNTs are the preferred choice for cost-effective, large-scale thermal enhancement in composites, fluids and TIMs.

Table 2: Comparison of Applications of SWCNT and MWCNT across different engineering domains:

Application Domain	SWCNT	MWCNT
Transistors and Logic Devices	Preferred due to semiconducting behavior and bandgap	Not suitable; metallic walls interfere with switching
Interconnects and Wires	High conductivity, but harder to purify and align	Practical due to size and ease of contact
Transparent Conductive Films	Excellent transparency and conductivity; ideal for flexible displays	Lower transparency; used when cost matters
Sensors	High sensitivity, suitable for single-molecule detection	Robust and widely used in bulk electrochemical sensors
Photonics and Quantum Devices	Used due to chirality-defined optical properties	Not used due to lack of bandgap
Mechanical Reinforcement	High reinforcement potential if well dispersed	Excellent toughness due to 'sword-in-sheath' effect
High-Temp & Metal Composites	Fragile, degrade faster at high temp	Robust; outer wall protects inner tubes
Electrical & EMI Shielding	Lower loading needed for conductivity, but expensive	Used in industry; moderate performance at lower cost
Thermal Conductive Composites	High intrinsic conductivity, rare in bulk due to cost	Commonly used due to processing ease
Biomedical & Flexible Devices	Preferred for biocompatibility and NIR absorption	Less biocompatible; may cause inflammation
Li-ion Battery Conductive Additive	Superior conductivity, low loading; expensive	Industry standard due to cost and robustness
Li-ion Anode Material	High surface area and capacity; less scalable	Lower capacity, more inert carbon content
Hybrid Anodes (e.g., Si-CNT)	Very conductive; limited by cost and bundling	Common scaffold for Si; strong and stable
Supercapacitor Electrodes	High capacitance and power; lower internal resistance	More durable, easier to fabricate
Thermal Interface Materials	Best performance in aligned films; hard to process	Used commercially; easier to disperse
Phase Change Materials	Higher thermal enhancement at low loading; costly	Common for bulk use; good balance of cost/performance
Nanofluids	Higher thermal conductivity; stability is a challenge	More stable dispersion; used in practice
Thermal	Effective but rarely used due to cost	Common due to low cost and good

Expansion Control		performance

Conclusion

The comparative analysis of single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) highlights a fundamental trade-off in materials engineering: peak performance versus practical deployability. SWCNTs, composed of a single graphene sheet rolled into a cylindrical form, offer extraordinary properties, tuneable electronic behavior (metallic or semiconducting), high charge mobility, exceptional tensile strength, large surface area and superior thermal conductivity. In contrast, MWCNTs, made of multiple concentric graphene cylinders, forgo some of that precision but offer greater mechanical resilience, easier processing and crucially, economic scalability.

In electronics, SWCNTs enable functionalities that MWCNTs simply cannot replicate. Their distinct electronic structure has led to the development of high-performance field-effect transistors and ultra-sensitive sensors. In composite materials, energy storage and conductive applications, both SWCNTs and MWCNTs improve material properties, but MWCNTs have emerged as the more practical solution due to lower cost and better processability. In thermal management, the picture is more nuanced: while SWCNTs offer superior intrinsic conductivity, MWCNTs often deliver better results in composites due to more reliable dispersion and network formation.

Research from 2020–2025 has sharpened our understanding of these materials. Studies have quantified the percolation thresholds, reinforcement efficiencies and electronic behaviors of CNTs, affirming that SWCNTs percolate and conduct at lower loadings, while chirality plays a critical role in their electrical properties. Importantly, this body of work has also emphasized the primacy of cost and scalability in real-world applications. MWCNTs dominate not because they are always better, but because they are more accessible. Innovations such as chirality sorting and alignment techniques for SWCNTs and advanced functionalization strategies for MWCNTs, have helped mitigate limitations and further optimized their respective applications.

Rather than positioning SWCNTs and MWCNTs as rivals, it is more accurate to view them as complementary components in the nano materials toolkit. Hybrid approaches, for example, materials that combine both types to exploit their respective advantages, are likely to gain ground. Should SWCNT production become more cost-effective, we may see broader adoption in domains now dominated by MWCNTs, unlocking new performance levels. Conversely, ongoing innovation in MWCNT architecture (e.g., alignment, 3D frameworks) could sustain and even expand their dominance in applied sectors.

In conclusion, the choice between SWCNTs and MWCNTs reflects the essence of engineering judgment: balancing theoretical performance with economic and processing realities. By leveraging a clear understanding of their respective strengths and limitations, engineers and material scientists can make informed decisions that maximize impact. As research and production technologies evolve, both SWCNTs and MWCNTs will remain vital to the advancement of carbon-based technologies. Each excelling in the applications for which they are uniquely suited, from nanoelectronics to thermal systems, energy storage to high-performance composites.

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