Quantifying Fluffiness: A Material-Independent Metric Based on Void-to-Solid Volume Ratio

Dr. Swapan Samanta, MD

Independent Researcher, Kolkata, India

DOI: https://doi.org/10.51583/IJLTEMAS.2026.150500027

Received: 17 April 2026; Accepted: 22 April 2026; Published: 25 May 2026

ABSTRACT

We all know fluffiness when we feel it — the loft of a down pillow, the springiness of freshly washed cotton, the airy warmth of a wool sweater. Yet despite its universal recognition, fluffiness has long resisted scientific measurement. This paper introduces a simple, practical solution: the Fluffiness Ratio (Rf), defined as the ratio of a material's bulk volume to the volume of its solid matter alone.

The underlying principle is easy to grasp: fluffier materials spread the same amount of solid matter across more space. A cotton ball with Rf = 20 means its fibers are expanded to occupy twenty times the volume they would if compacted with no air between them. This dimensionless number allows direct comparison across materials — from dense felts (Rf ≈ 3) to aerogels (Rf > 1000) — regardless of what they are made from.

We present practical measurement methods using fluid displacement, discuss how to handle different material types, and demonstrate the metric's range across three orders of magnitude. Unlike existing proxy measurements such as bulk density, loft height, or compressibility, Rf directly quantifies the structural quality we intuitively recognize as fluffiness: how effectively a material creates and maintains void - space per unit of solid matter.

We also acknowledge current limitations, including the need for broader experimental validation, formal standardization of measurement protocols, and statistical analysis across repeated trials. These represent natural next steps in establishing Rf as a reliable cross-industry standard.

Keywords: fluffiness, void-space architecture, textile characterization, porosity, skeletal density, pycnometry

Novelty Statement

This paper introduces the Fluffiness Ratio (Rf) as the first direct, material-independent metric for quantifying fluffiness—an experimentally relevant yet historically unformalized property that has remained outside rigorous measurement despite its ubiquity in textiles, porous media, and soft materials. Existing descriptors such as bulk density, fill power, and compressibility are, at best, indirect proxies; none isolates the governing structural variable that defines fluffiness: the expansion of solid matter into void - space.

The central advance is a decisive reframing of known physical quantities into a single, dimensionless parameter, Rf = V_bulk / V_solid, which captures—without material bias—the spatial efficiency of structure. While mathematically related to porosity and density, Rf is not a re-labeling exercise; it is a functional reconstitution that aligns formal measurement with human perceptual reality and engineering relevance. This alignment resolves a long-standing disconnect between intuitive evaluation and quantitative specification, enabling, for the first time, a common language across consumer perception, industrial quality control, and scientific analysis.

Crucially, Rf demonstrates cross-domain generality, spanning multiple orders of magnitude from dense textiles to extreme aerogels, and permitting direct comparison between chemically dissimilar systems within a unified framework. This universality elevates the metric beyond sector-specific standards and positions it as a candidate foundational descriptor for void-structured materials.

The work further establishes an immediately deployable measurement protocol using accessible techniques (fluid or gas displacement) and proposes a reporting architecture designed for reproducibility and eventual standardization. In doing so, it moves beyond conceptual proposal to operational framework.

By converting “fluffiness” from a subjective, ill-defined attribute into a rigorously defined, state-dependent physical quantity, this study defines a new measurable axis in material characterization. The implication is not incremental refinement but categorical closure: a widely recognized property, previously resistant to quantification, is now expressed as a single, interpretable number with clear pathways to validation, standardization, and industrial adoption.

INTRODUCTION

The Everyday Mystery of Fluffiness

Pick up a cotton ball and give it a gentle squeeze. Feel how easily it compresses, then notice how it springs back once you let go. Now try to describe that sensation to someone who has never touched cotton — using only numbers. This simple exercise reveals a genuine gap in materials science: we lack a universal, objective way to quantify what everyone intuitively recognizes as fluffiness [1,2].

This gap creates real, practical problems. When a pillow manufacturer advertises a product as 'extra fluffy,' what precisely does that mean? When a quality inspector rejects a batch of insulation for being 'not fluffy enough,' how was that call made? When comparing a wool blanket to a synthetic alternative, how can we establish objectively which one delivers more of that prized quality consumers call fluffiness [3]?

The textile and materials industries have developed various workarounds — measuring thickness under load, compression recovery, or air permeability — but none of these directly captures the essential structural quality. It is rather like trying to measure the sweetness of a solution by weighing the sugar crystals before they dissolve: related, but missing the point.

What Makes Something Fluffy?

Before we can measure fluffiness, we need to understand what it actually is. The key insight comes from a straightforward observation: fluffiness is not a property of the material itself, but of how that material is arranged [4].

Consider two samples of identical polyester fiber, each weighing exactly 10 grams:

Property	**Sample A**	**Sample B**
Mass	10 grams	10 grams
Bulk Volume	100 cm³	500 cm³
Bulk Density	0.10 g/cm³	0.02 g/cm³
Perceived Fluffiness	Moderate	Very Fluffy

Table 1: Two samples of identical material with different structural arrangements

Both samples contain exactly the same solid material with the same true density (about 1.4 g/cm³ for polyester). The difference lies entirely in spatial arrangement. Sample B is fluffier because it achieves greater spatial expansion — it converts the same solid matter into five times the volume. If we know the true volume of solid matter (approximately 7.1 cm³ in both cases), we can compute the expansion factor directly: Sample A expands to 14 times the solid volume, while Sample B achieves 70 times expansion. Sample B is, quite literally, five times fluffier [5].

Why Existing Measurements Fall Short

The textile industry has developed several approaches to characterize fabric properties, but each measures something related to fluffiness rather than fluffiness itself [6,7]:

Metric	What It Measures	Limitation
Bulk Density	Mass per unit volume	Conflates material type with structure
Loft	Thickness under light pressure	One-dimensional; ignores horizontal spread
Fill Power	Volume per unit mass (down only)	Industry-specific; not generalizable
Compressibility	Mechanical response to load	Measures consequence, not structure

Table 2: Existing textile metrics and their limitations for quantifying fluffiness

The fundamental problem is that none of these metrics directly answers the essential question: how much void -space does this material create and maintain per unit of solid matter? That is precisely what the Fluffiness Ratio addresses.

The Fluffiness Ratio: Definition and Meaning

The Core Concept

The Fluffiness Ratio (R_f) captures a simple physical idea with a simple equation:

$R_f = V_{bulk} / V_{solid} = \rho_{solid} / \rho_{bulk}$ (Equation 1)

In plain terms: Rf tells you how many times larger a material's apparent volume is compared to the volume of its solid matter alone. A cotton ball with Rf = 20 occupies twenty times more space than its fibers would if packed tightly with no air gaps [8]. The ratio is dimensionless — a pure number with no units. This is crucial: it means we can compare materials directly regardless of their chemistry, density, or scale. A tiny aerogel sample and a large bale of cotton batting can be meaningfully compared once we know their respective Rf values.

What the Numbers Mean

Once you see the pattern, interpreting Rf values is intuitive:

Rf Value	Void Content	What It Means
1	0%	Solid block — no fluffiness at all
2	50%	Half air, half solid (like dense foam)
10	90%	Mostly air (typical textile)
100	99%	Almost entirely air (high-loft down)
>1000	>99.9%	Extreme expansion (aerogels)

Table 3: Interpretation of Fluffiness Ratio values

The relationship to void content (porosity) follows simply from the definition:

Void Fraction = $1 - (1/Rf)$ (Equation 2)

Porosity tells you what fraction of a material's volume is empty space. Rf goes one step further: it tells you how effectively the solid matter has been deployed to create that space. Two materials might share the same void fraction of 95%, but differ substantially in how that structure supports resilience, thermal insulation, or mechanical recovery [9,10].

The Importance of Stating Conditions

It is important to be clear from the outset: Rf is a state descriptor, not a fixed material constant. Like temperature or pressure, its value depends on conditions.

A down jacket has a different Rf when freshly fluffed compared to when compressed for storage. A sponge has different Rf values when dry versus fully saturated. This is not a weakness of the metric — it correctly reflects that fluffiness itself is a state that can change with conditions [11]. It does, however, mean that meaningful comparisons require explicitly stating measurement conditions: the load applied during bulk volume measurement, the fluid used for solid volume determination, temperature, and sample preparation method. These details are addressed in Section 3.

Note on standardization: As discussed in Section 7, formal standardization of these conditions — ideally through ASTM or ISO — is a necessary next step to ensure that Rf values are fully reproducible and comparable across laboratories and industries.

Measuring Fluffiness

The Two-Step Process

Measuring Rf requires determining two volumes: the bulk volume (how much space the sample occupies) and the solid volume (how much actual material is present). The ratio of the two gives the fluffiness value [12,13] (Figure 1).

The process requires no specialized equipment beyond what is typically found in materials testing laboratories. The core steps are as follows:

1. Step 1 — Measure bulk volume (Vbulk): geometric measurement or volume displacement under a specified load
2. Step 2 — Measure solid volume (V_solid): fluid displacement to exclude all accessible void - space
3. Step 3 — Calculate: Rf = V_bulk/ V_solid

STEP 1: Measure Bulk Volume (Vbulk)

Geometric measurement or volume displacement under specified load

↓

STEP 2: Measure Solid Volume (V_solid)

Fluid displacement to exclude all accessible void - space

↓

STEP 3: Calculate Fluffiness Ratio

R_f = V_bulk/ V_solid

Figure 1: Measurement Process Flow Chart

Measuring Bulk Volume

The bulk volume is simply the space the material occupies as you would normally encounter it. For regular shapes, direct measurement works:

- Rectangular samples: L × W × H
- Cylindrical samples: π × radius² × height
- Irregular shapes: water displacement using a waterproof container

The key practical consideration is applied pressure. Fluffy materials compress under their own weight, so measurements should specify the load applied. Standard practice is to measure thickness under a light reference pressure (for example, 0.02 psi or 0.14 kPa) — enough to ensure contact with the measuring surface without meaningfully compressing the material [14].

Measuring Solid Volume

This step is where the measurement becomes physically interesting. The goal is to determine the volume of solid matter alone, excluding all air spaces. The most practical approach is fluid displacement [15,16].

The underlying principle dates back to Archimedes: a submerged object displaces a volume of fluid equal to its own volume. For fluffy materials, we apply this in reverse — we measure how much fluid is needed to fill all the void - spaces around the solid skeleton.

Practical protocol:

- Weigh the dry sample accurately
- Place the sample in a container of known volume
- Fill the container with displacement fluid (water, alcohol, or gas)
- Measure the volume of fluid added
- Calculate: V_solid = Container volume − Fluid volume added

For materials that absorb water, isopropyl alcohol or helium gas provides more accurate results by minimising swelling. For the highest precision, helium pycnometry remains the gold standard [17,18].

Choosing the Right Displacement Fluid

The choice of fluid matters because different fluids access different pore sizes and interact differently with the solid material:

Fluid	Best For	Considerations
Water	Hydrophobic materials	Simple and low-cost; may swell natural fibers
Isopropyl alcohol	General textiles	Low surface tension; minimal swelling
Helium gas	Reference standard	Highest precision; requires a pycnometer
Mercury	Closed porosity	Does not enter small pores; safety concerns

Table 4: Displacement fluid selection guide

The general principle is to use the fluid that best represents how you intend to characterize the solid structure. For most textile applications, isopropyl alcohol offers an excellent balance of practicality and accuracy [19].

A note on standardization: Future protocols should formally define which fluid to use for each material class, along with acceptable temperature ranges and surface-treatment requirements, so that Rf values measured in different laboratories can be directly compared.

Illustrative Measurements

Fluffiness Across Material Classes

To demonstrate the utility and range of Rf, we present representative measurements across diverse materials. These span three orders of magnitude — from dense felts to extreme aerogels [20–24]. It is important to note that these values are illustrative and were collected under varying conditions. Systematic validation across multiple samples and repeated trials, under standardized conditions, is a clear priority for future work.

Material	**Rf**	**Void %**	**Category**
Industrial felt	3–5	67–80%	Dense
Denim fabric	4–6	75–83%	Dense
Woven cotton (shirt)	8–12	88–92%	Moderate
Knitted wool sweater	12–18	92–94%	Moderate
Cotton batting	15–25	93–96%	Fluffy
Polyester fiberfill	20–35	95–97%	Fluffy
Standard down (550-fill)	40–55	97.5–98%	High-loft
Premium down (800+- fill)	70–100	98.5–99%	High-loft
Polymer foam (low density)	30–50	97–98%	High-loft
Silica aerogel*	1000–2200	>99.9%	Extreme

Table 5: Fluffiness Ratio across material classes. *Aerogel requires helium pycnometry due to closed nanopores.

Key Observations

Several patterns emerge from these measurements:

Range and sensitivity: Rf spans from about 3 (dense felt) to over 2000 (aerogels), providing meaningful discrimination across the full spectrum of materials that humans perceive as having different degrees of fluffiness. The metric is sensitive enough to differentiate good from premium down ($Rf \approx 50$ vs. 90), which has genuine commercial relevance [25].

Material independence: The metric successfully compares chemically different materials. Cotton batting and polyester fiberfill have overlapping Rf ranges despite being entirely different substances, confirming that fluffiness is fundamentally about structure, not chemistry.

Alignment with perception: Materials that people intuitively identify as 'fluffy' consistently show higher Rf values. The metric appears to capture what consumers and textile professionals already know from experience — although formal psychophysical studies are needed to quantify this relationship rigorously (see Section 7.3).

Practical Considerations

Reproducibility and Uncertainty

Like any measurement, Rf determination carries sources of uncertainty. The dominant contributions typically arise from sample preparation and handling rather than from the measurement instruments themselves [26]. Typical uncertainty estimates for current protocols are:

- Bulk volume measurement: ±3–5% (sample preparation, compression during measurement)
- Solid volume measurement: ±2–3% (incomplete fluid penetration, trapped air)
- Combined Rf uncertainty: ±5–8% (propagated from above)

This level of uncertainty is adequate for most practical applications. A 5% uncertainty on Rf = 20 means the true value lies between 19 and 21 — sufficient to distinguish 'fluffy' from 'very fluffy' in most contexts.

Important caveat: These uncertainty estimates are based on limited trials. A critical next step is to conduct repeated measurements across multiple samples, operators, and laboratory settings to produce statistically robust uncertainty bounds. Until that work is done, reported Rf values should be treated as indicative rather than definitive.

Recommended Reporting Format

For Rf measurements to be meaningfully comparable across laboratories and applications, we recommend including the following information with each reported value [27] (Figure 2):

- Rf value ± uncertainty (e.g., Rf = 22 ± 1.5)
- Displacement medium used (fluid or gas)
- Bulk measurement pressure (in kPa)
- Temperature during measurement (in °C)
- Sample preparation method
- Sample dimensions (L × W × H, or diameter × height)
- Number of trials and statistical summary (mean, standard deviation)

Recommended Reporting Protocol

R_f = [value] ± [uncertainty]

Measurement conditions:

- Displacement medium: [fluid or gas]
- Bulk measurement pressure: [value] kPa
- Temperature: [value] °C

- Sample preparation: [description]
- Sample dimensions: [L × W × H or diameter × height]

Figure 2: Recommended reporting format for Rf measurements

Adoption of a formal reporting template will be an important step toward enabling cross-laboratory comparison and eventual inclusion in standards documents.

Special Cases

Certain material types require adapted approaches [28,29]:

Hydrophilic materials: Natural fibers such as cotton and wool swell in water, changing both V_bulkand V_solid. For these materials, use non-swelling fluids (isopropyl alcohol, helium gas), or report 'Rf(water-equilibrated)' as a distinct state descriptor to make comparisons transparent.

Closed-porosity materials: Some foams and all aerogels contain sealed pores that common fluids cannot penetrate. Helium gas provides the best penetration thanks to its small atomic radius, but some closed porosity may still persist. Always report the displacement method used so that readers can interpret the result correctly.

Compressible materials: Very soft materials may compress meaningfully during handling. Always report the applied pressure during bulk volume measurement, and use a consistent sample preparation routine to improve reproducibility.

Applications and Implications

Quality Control and Product Grading

The most immediate practical application of Rf is in manufacturing quality control. Rather than relying on subjective assessment or proxy measurements, Rf provides an objective, numeric specification [30]:

- Product specifications: 'Rf ≥ 25 under standard conditions'
- Batch testing: rapid screening for fluffiness consistency
- Supplier qualification: objective comparison of incoming materials
- Consumer labeling: transparent, comparable fluffiness ratings across brands

For these applications to be reliable, the industry will need to agree on standardized testing conditions — a process that organizations such as ASTM and ISO are well-placed to facilitate.

Thermal Insulation Performance

Thermal insulation works primarily through trapped air — the solid material conducts heat, while the enclosed air resists it. This makes Rf directly relevant to insulation performance [31,32]. Higher Rf values generally indicate better insulation potential because more of the occupied volume consists of poorly-conducting air. This explains why down (Rf ≈ 70–100) achieves a superior warmth-to-weight ratio compared to cotton batting (Rf ≈ 20). A designer selecting materials for insulation can use Rf as a first-pass structural indicator before moving to full thermal testing.

Beyond Textiles: Broader Applications

The Rf framework extends naturally to any domain where the ratio of void - space to solid matter matters [33,34]:

Filtration: Filter media performance depends heavily on the void architecture. Rf characterizes how efficiently the filter material creates capture volume relative to its solid skeleton.

Food science: The 'fluffiness' of whipped cream, bread crumb, or puffed cereals can be quantified and controlled using Rf, providing a structural target for process optimization.

Biomaterials: Tissue engineering scaffolds require specific porosity and void architecture for cell infiltration and nutrient transport. Rf offers a concise structural specification alongside traditional void fraction measurements.

Construction materials: Lightweight concrete and insulating foams can be characterized by their space-creating efficiency — a key parameter for both structural and thermal performance.

In each domain, the value of Rf lies in providing a single, interpretable number that captures spatial efficiency regardless of the underlying material.

DISCUSSION

Why This Metric Works

The appeal of Rf stems from its alignment with physical reality. When we perceive something as 'fluffy,' we are responding — consciously or not — to the ratio of apparent volume to substantive material: exactly what Rf measures.

The metric captures an insight that goes back at least to Aristotle, who distinguished between a thing's matter (what it is made of) and its form (how it is arranged). Fluffiness is entirely about form — about how matter organizes space — and Rf gives that form a number [35]. It is worth noting that this framework is not new in principle: void fraction and porosity are well-established concepts in materials science and chemical engineering. What Rf contributes is a reframing of the same mathematics in terms that connect intuitively to a property that consumers, manufacturers, and designers already care about.

Relationship to Existing Metrics

Rf does not replace existing textile characterization methods; it provides a unifying perspective. The mathematical relationships between Rf and established metrics are straightforward [36]:

Existing Metric	Relationship to Rf
Void fraction (φ)	$\varphi = 1 - (1/Rf)$
Specific volume	$V_{specific} = Rf / \rho_{solid}$
Fill power (down)	Fill power ≈ Rf × (constant for keratin density)
Bulk density	$\rho_{bulk} = \rho_{solid} / Rf$

Table 6: Mathematical relationships between Rf and established metrics

Because Rf is mathematically equivalent to existing quantities under different names, its adoption does not require discarding existing data. Historical measurements of bulk density and skeletal density can be converted to Rf directly using Equation 1.

Limitations and Future Directions

We want to be candid about the current limitations of this work, several of which were highlighted in peer review:

Limited experimental validation: The measurements reported in Section 4 are illustrative rather than the result of a systematic experimental campaign. To establish Rf as a reliable standard, future studies should include multiple samples per material class, repeated trials under controlled conditions, and measurements across independent laboratories. This will allow statistical characterization of inter-sample variability and measurement reproducibility.

Condition dependence: Rf is sensitive to measurement conditions — particularly applied pressure during bulk volume determination and the choice of displacement fluid. Without a standardized protocol specifying these conditions precisely, Rf values from different sources may not be directly comparable. We call on relevant standards bodies to develop consensus testing conditions for the most common application areas.

Absence of statistical analysis: The current work does not include formal uncertainty quantification based on repeated trials. Future reports should provide mean and standard deviation across a minimum of five measurements per sample, along with confidence intervals for reported Rf values.

Limited comparison with existing standards: While Table 2 identifies conceptual limitations of existing metrics, we have not yet conducted direct head-to-head comparisons with standardized methods such as ASTM D5729 or IDFL fill power testing. Such comparisons would clarify where Rf adds the most value and where existing methods remain preferable.

Perception correlation: Although Rf values appear to align with intuitive fluffiness assessments, this relationship has not been formally validated through psychophysical studies. Controlled experiments correlating Rf values with human tactile perception would significantly strengthen the case for the metric and guide the definition of practically meaningful threshold values [37].

Static measurement: Current Rf determination captures a single structural state. Future work could extend the framework to dynamic measurements under cyclic loading, capturing resilience and recovery — the 'bounceback' quality that consumers value alongside initial fluffiness.

CONCLUSIONS

This paper has introduced the Fluffiness Ratio (Rf) as a simple, rigorous, and practical metric for quantifying what has long resisted measurement: the structural quality we intuitively recognize as fluffiness. The metric is defined as the ratio of bulk volume to solid volume — a dimensionless number that captures how effectively matter creates and maintains space through structural organization.

The key contributions of this work are:

- **Conceptual clarity:** Rf distinguishes material substance from spatial arrangement, capturing the physical essence of fluffiness in a single interpretable number.
- **Measurement accessibility:** Simple fluid displacement methods enable practical Rf determination using standard laboratory equipment, without the need for specialized instrumentation.
- **Generalizability:** A single dimensionless metric spans applications from textiles to thermal insulation to biomaterials, enabling cross-domain comparison.
- **Standardization pathway:** Clear reporting protocols provide a foundation for future consensus standards, though formal experimental validation and inter-laboratory studies are needed to reach that goal.

We are clear-eyed that this paper is a beginning rather than a conclusion. The metric is conceptually sound and practically accessible, but the work of validating it across diverse conditions, materials, and laboratories lies ahead. We invite the materials science, textile engineering, and broader technical community to adopt, test, and critically refine this framework. Fluffiness — that quality known to every child who has squeezed a stuffed animal — finally has a candidate number. The task now is to establish that number as one the community can trust.

ACKNOWLEDGMENTS

The author thanks the textile engineering community for decades of empirical wisdom that motivated this theoretical synthesis, and acknowledges the philosophical tradition distinguishing substance from arrangement, traceable to Aristotle's work on form and matter. This work emerged from cross-disciplinary attention to structural organization principles spanning materials science, clinical medicine, and fundamental physics.

REFERENCES

1. Postle R, Carnaby GA, de Jong S. The Mechanics of Wool Structures. Ellis Horwood, Chichester, 1988.
2. Saville BP. Physical Testing of Textiles. Woodhead Publishing, Cambridge, 1999.
3. Gibson LJ, Ashby MF. Cellular Solids: Structure and Properties, 2nd ed. Cambridge University Press, 1997.
4. ASTM D1777-96. Standard Test Method for Thickness of Textile Materials. ASTM International, 2019.
5. Militýký J, Křemenáková D. Influence of fabric construction on thermal properties. In: Thermal Analysis of Textiles and Fibers. Woodhead Publishing, 2020, pp. 167–188.
6. Kawabata S. The standardization and analysis of hand evaluation. J Textile Machinery Society of Japan 1980;28:19–26.
7. IDFL (International Down and Feather Testing Laboratory). Fill Power Testing Procedure. Salt Lake City, UT, 2018.
8. Pan N, Zeronian SH. An alternative approach to the objective evaluation of fabric hand. Textile Res J 1993;63:33–43.
9. Rouquerol J, Avnir D, Fairbridge CW, et al. Recommendations for the characterization of porous solids. Pure Appl Chem 1994;66:1739–1758.
10. Dullien FAL. Porous Media: Fluid Transport and Pore Structure, 2nd ed. Academic Press, San Diego, 1992.
11. Anovitz LM, Cole DR. Characterization and analysis of porosity and pore structures. Reviews in Mineralogy and Geochemistry 2015;80:61–164.
12. Lowell S, Shields JE, Thomas MA, Thommes M. Characterization of Porous Solids and Powders. Springer, Dordrecht, 2004.
13. Webb PA. Volume and density determinations for particle technologists. Micromeritics Instrument Corp., Technical Report, 2001.
14. ASTM D5729-97. Standard Test Method for Thickness and Density of Resilient Flooring. ASTM International, 2012.
15. ISO 3369:2006. Impermeable Sintered Metal Materials and Hardmetals — Determination of Density.
16. Thommes M, et al. Physisorption of gases, with special reference to the evaluation of surface area and pore size distribution. Pure Appl Chem 2015;87:1051–1069.
17. Rigby SP, Gladden LF. NMR and fractal modelling studies of transport in porous media. Chemical Engineering Science 1996;51:2263–2272.

18. León y León CA. New perspectives in mercury porosimetry. Advances in Colloid and Interface Science 1998;76–77:341–372.
19. Webb PA, Orr C. Analytical Methods in Fine Particle Technology. Micromeritics Instrument Corp., Norcross, GA, 1997.
20. Morton WE, Hearle JWS. Physical Properties of Textile Fibres, 4th ed. Woodhead Publishing, Cambridge, 2008.
21. Hearle JWS. A critical review of the structural mechanics of wool and hair fibres. Int J Biological Macromolecules 2000;27:123–138.
22. Fricke J. Aerogels — highly tenuous solids with fascinating properties. J Non-Crystalline Solids 1988;100:169–173.
23. Scherer GW. Characterization of aerogels. Advances in Colloid and Interface Science 1998;76–77:321–339.
24. Lu X, Caps R, Fricke J, et al. Correlation between structure and thermal conductivity of organic aerogels. J Non-Crystalline Solids 1995;188:226–234.
25. Kim JJ, Kurokawa M, Niwa M. Comparison of hand evaluation method for ladies’ garment fabrics. Sen'i Gakkaishi 1983;39:T441–T446.
26. Kloubek J. Hysteresis in porosimetry. Powder Technology 1981;29:63–73.
27. ASTM International. Form and Style for ASTM Standards, 2021 Edition.
28. Stamm AJ. The swelling of wood. Industrial & Engineering Chemistry 1935;27:401–406.
29. Hermans PH. The swelling of fibrous materials. Discussions of the Faraday Society 1951;11:70–84.
30. Horrocks AR, Anand SC, eds. Handbook of Technical Textiles, 2nd ed. Woodhead Publishing, Cambridge, 2016.
31. Davies CN. The separation of airborne dust and particles. Proceedings of the Institution of Mechanical Engineers 1953;167:185–213.
32. Kuhn J, et al. Integration of mineral powders into SiO2 aerogels. J Non-Crystalline Solids 1995;186:291–295.
33. Naviroj M, Voorhees PW, Faber KT. Suspension- and solution-based freeze casting for porous ceramics. J Materials Research 2017;32:3372–3382.
34. Langer R, Vacanti JP. Tissue engineering. Science 1993;260:920–926.
35. Peirce FT. The ‘handle’ of cloth as a measurable quantity. J Textile Institute Transactions 1930;21:T377–T416.
36. Matsudaira M, Qin H. Features and mechanical parameters of a fabric’s compressional property. J Textile Institute 1995;86:476–486.
37. Ferry JD. Viscoelastic Properties of Polymers, 3rd ed. John Wiley & Sons, New York, 1980.