IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

# Aerogel: A Solid Gas Material Straight From Space To Architecture

UTSAH JAIN

MRS. SUCHETA NIGAM ASSOCIATE PROFESSOR
SCHOOL OF ARCHITECTURE PLANNING AND DESIGN,
SANJEEV AGRWAL GLOBAL EDUCATION UNIVERSITY (SAGE), BHOPAL

***ABSTRACT:*** AEROGEL HAS QUICKLY BECOME ONE OF THE MOST EXCITING MATERIALS IN SCIENCE AND ENGINEERING TODAY. LOVED FOR BEING INCREDIBLY LIGHTWEIGHT AND AN OUTSTANDING INSULATOR, AEROGEL'S JOURNEY IS REMARKABLE—FROM A SCIENTIFIC NOVELTY TO A TRUE GAME-CHANGER IN FIELDS AS VARIED AS AEROSPACE, BUILDING CONSTRUCTION, AND SUSTAINABLE DESIGN. THIS PAPER TAKES A CLOSE LOOK AT HOW AEROGEL WAS DISCOVERED, HOW IT WORKS, AND WHY ITS UNUSUAL STRUCTURE MAKES IT SO VALUABLE. WE ALSO EXPLORE ITS MANUFACTURING PROCESSES, CURRENT REAL-WORLD USES, THE CHALLENGES IT FACES, AND WHERE RECENT INNOVATIONS SEEM TO BE LEADING. WITH NEW RESEARCH AND TECHNOLOGY POINTING TOWARD MORE AFFORDABLE AND SUSTAINABLE PRODUCTION, AEROGEL'S FUTURE LOOKS BOTH BRIGHT AND WIDESPREAD.

***INDEX TERMS*** - AEROGEL, INSULATION, SUSTAINABLE MATERIAL, ARCHITECTURE, AEROSPACE, BIOMASS-DERIVED, NANOSTRUCTURE

## I. INTRODUCTION

AEROGEL, OFTEN PLAYFULLY CALLED "FROZEN SMOKE" OR "SOLID AIR," TRULY LIVES UP TO THESE NICKNAMES. ITS FEATHER-LIGHT WEIGHT COMES FROM A SPONGE-LIKE STRUCTURE FILLED WITH TINY NANOPORES THAT TRAP AIR. FIRST MADE BY STEVEN S. KISTLER IN 1931 BY REPLACING A GEL'S LIQUID WITH AIR WHILE KEEPING ITS SHAPE, AEROGEL HAS SINCE UNDERGONE BIG CHANGES. EARLY SILICA AEROGEL FOUND ITS WAY INTO SPECIALTY PANELS AND INSULATION FOR LABS AND SPACECRAFT BY THE LATE 20TH CENTURY, BUT THE STORY DIDN'T STOP THERE. RESEARCHERS HAVE DEVELOPED AEROGELS BASED ON POLYMERS, CARBON, AND EVEN HYBRID BLENDS, EACH OPENING NEW APPLICATIONS AND SOLVING NEW CHALLENGES.

## II. LITERATURE REVIEW

RECENT RESEARCH HAS REVEALED THE REMARKABLE RANGE AND GROWING PRACTICAL VALUE OF AEROGELS:

- **DATA-DRIVEN AEROGELS (2025):** SCIENTISTS TODAY USE DATA AND COMPUTATION TO FINE-TUNE THE PRODUCTION AND PROPERTIES OF TOUGH, FLEXIBLE AEROGELS, ADDRESSING ISSUES LIKE BRITTLENESS.
- **SUSTAINABLE BIOMASS AEROGELS (2025):** NEW AEROGELS MADE FROM THINGS LIKE CELLULOSE AND LIGNIN (FROM PLANTS AND AGRICULTURAL WASTE) HAVE LOWER ENVIRONMENTAL IMPACT AND MAKE SMART USE OF RESOURCES.
- **HIGH-TEMPERATURE AEROGELS (2024):** POLYIMIDE OR ALUMINA-BASED AEROGELS WITHSTAND INTENSE HEAT, MAKING THEM WELL-SUITED FOR AEROSPACE, ENGINES, AND POWER PLANTS.
- **HYBRID AND FLEXIBLE AEROGELS (2023):** BLENDING MATERIALS LIKE GRAPHENE OR CARBON NANOTUBES GIVES AEROGELS UNUSUAL FLEXIBILITY AND ELECTRICAL CONDUCTIVITY, SO THEY CAN BE USED IN SHIELDING, SENSORS, OR AS PART OF WEARABLE TECH.

- **NEW PREPARATIONS:** INNOVATIONS SUCH AS DOUBLE CROSSLINKING MAKE AEROGELS STRONGER AND MORE TRANSPARENT, BETTER SUITING THEM TO CONSTRUCTION AND ELECTRONICS.

**PROBLEM STATEMENT**

GLASS REMAINS THE DEFAULT FOR WINDOWS, PARTITIONS, AND BASIC INSULATION, BUT IT'S FAR FROM PERFECT GLASS CAN CRACK UNDER STRESS, IS HEAVY, AND NEEDS CAREFUL HANDLING. EVEN IMPROVED VERSIONS, LIKE TEMPERED OR LAMINATED GLASS, CAN BREAK AND POSE CHALLENGES FOR DESIGN AND SAFETY. ALTERNATIVES LIKE MINERAL WOOL OR FOAM OFFER INSULATION, BUT OFTEN BRING TRADE-OFFS IN TERMS OF WEIGHT, FIRE SAFETY, OR ENVIRONMENTAL IMPACT. WITH GROWING NEEDS FOR BETTER AND SAFER BUILDING MATERIALS, IT'S TIME TO EXPLORE NEW SOLUTIONS LIKE AEROGELS, WHICH COMBINE ROBUST INSULATION, SAFETY, AND MUCH MORE FLEXIBILITY.

**AIM AND OBJECTIVES**

**AIM:**

TO THOROUGHLY EXPLORE THE POTENTIAL OF AEROGEL AS A RADICALLY BETTER OPTION THAN FAMILIAR INSULATORS LIKE GLASS, IN BOTH BUILDINGS AND INDUSTRY.

**OBJECTIVES:**

- SHOW HOW AEROGEL AND NEXT-GEN MATERIALS CAN FIT INTO DAILY LIFE AND PROFESSIONAL PRACTICE.
- SUPPORT ECO-AWARE ARCHITECTURE BY OFFERING CREDIBLE ALTERNATIVES TO STANDARD INSULATORS.
- HIGHLIGHT UNIQUE APPLICATIONS—LIKE DAYLIGHTING, ULTRA-THIN INSULATION, AND MODERN DESIGN—THAT REALLY SHOWCASE WHAT AEROGEL CAN DO.
- ENCOURAGE ARCHITECTS, ENGINEERS, AND DESIGNERS TO CONSIDER AEROGEL BOTH FOR PERFORMANCE AND CREATIVE EXPRESSION.

**SCOPE**

AEROGEL'S WORLD IS WIDE, COVERING:

- **MAKING IT SCALABLE & SUSTAINABLE:** ADVANCES IN HOW AEROGELS ARE MADE—USING METHODS LIKE SOL-GEL CHEMISTRY AND RECYCLED FEEDSTOCKS—PROMOTE AFFORDABILITY AND ECO-FRIENDLINESS.
- **FLEXIBLE & TRANSPARENT FORMS:** MODERN AEROGELS CAN BE NEARLY INVISIBLE AND BENDABLE, FITTING EASILY INTO SMART WINDOWS, LIGHTING PANELS, AND EVEN FLEXIBLE GADGETS.
- **BLENDED AEROGELS:** ADDING MATERIALS LIKE NANOFIBERS OR GRAPHENE MAKES AEROGELS TOUGHER, MORE CONDUCTIVE, OR SPECIFICALLY TAILORED FOR ELECTRONICS AND ENGINEERING.
- **DESIGN INNOVATION:** THANKS TO THEIR SEE-THROUGH LOOK, LIGHT-DIFFUSING QUALITIES, AND TOP-NOTCH FIRE AND SOUND-RESISTANCE, AEROGELS ARE APPEARING IN EVERYTHING FROM WALL PANELS AND ACOUSTIC BAFFLES TO STATEMENT LIGHTING AND ARTISTIC INSTALLATIONS.

**LIMITATIONS**

EVEN WITH ALL THEIR PROMISE, AEROGELS AREN'T PERFECT YET:

- **HIGH COSTS:** STANDARD PRODUCTION STILL NEEDS PRICEY TECHNIQUES AND INGREDIENTS, MAKING AEROGEL COSTLIER THAN COMMON MATERIALS (THOUGH NEW METHODS ARE BRINGING PRICES DOWN).
- **BRITTLENESS:** MANY AEROGELS ARE FRAGILE, SO USING THEM WHERE REAL STRENGTH IS NEEDED MEANS THEY OFTEN REQUIRE SUPPORT OR LAMINATION.
- **GREEN CHEMISTRY:** THERE'S STILL WORK TO DO IN MAKING PRODUCTION TRULY SUSTAINABLE, SUCH AS USING GREENER INGREDIENTS AND PROCESSES.
- **DURABILITY:** QUESTIONS ABOUT HOW AEROGELS STAND UP TO SUNLIGHT, MOISTURE, AND TIME ARE BEING INVESTIGATED—THE ANSWERS WILL HELP GUIDE WIDER ADOPTION.

**RESULTS AND DISCUSSION**

AEROGEL'S SHIFT FROM LAB BENCH TO BUILDING SITE IS A STORY OF SMART SCIENCE AND INVENTIVE DESIGN. TODAY, AEROGEL PANELS OFFER INSULATION FAR SUPERIOR TO TRADITIONAL MATERIALS, WITH THIN, SEE-THROUGH SURFACES THAT KEEP INTERIORS BRIGHT AND ENERGY EFFICIENT. THEY'RE A STAPLE IN SPACE EXPLORATION, HANDLING EXTREME CONDITIONS WHERE NOTHING ELSE WILL DO. MEANWHILE, BREAKTHROUGHS IN PRODUCTION ARE MAKING THEM MORE ACCESSIBLE—NOT JUST FOR ENERGY-SAVING WALLS, BUT FOR WEARABLES, HIGH-PERFORMANCE CLOTHING, PACKAGING, AND MORE. THE ABILITY TO CREATE HYBRID AEROGELS WITH CUSTOM PROPERTIES MEANS APPLICATIONS IN ENERGY STORAGE, ELECTRONICS, AND CONSTRUCTION ARE GROWING EVERY YEAR.

**CONCLUSION**

AEROGEL ISN'T JUST A TECHNOLOGICAL LEAP—IT'S A MATERIAL THAT COULD RESHAPE HOW WE BUILD, INSULATE, AND DESIGN OUR WORLD. WITH MORE RESEARCH INTO AFFORDABILITY, TOUGHNESS, AND GREEN MANUFACTURING, AEROGEL'S PROMISE AS A MAINSTAY OF SUSTAINABLE ARCHITECTURE AND ADVANCED ENGINEERING IS CLOSER TO REALITY THAN EVER. AS DESIGNERS AND SCIENTISTS CONTINUE TO DISCOVER NEW USES AND COMBINATIONS, AEROGELS ARE LIKELY TO BECOME BOTH A PRACTICAL BUILDING BLOCK AND AN INSPIRATION FOR NEXT-GENERATION INNOVATION.

**REFERENCES**


1. IDTECHEX. "AEROGELS 2025-2035: TECHNOLOGY, MARKET, FORECASTS." IDTECHEX RESEARCH REPORT, 2025. HTTPS://WWW.IDTECHEX.COM/EN/RESEARCH-REPORT/AEROGELS-2025-2035-TECHNOLOGY-MARKET-FORECASTS/1076
2. SCIENCEDIRECT. "ENHANCED PERSPECTIVES ON SILICA AEROGELS: NOVEL SYNTHESIS, ADVANCED PROPERTIES AND APPLICATIONS." 2025. HTTPS://PMC.NCBI.NLM.NIH.GOV/ARTICLES/PMC10754877/
3. SCIENCEDIRECT. "REVIEW RESEARCH PROGRESS OF AEROGEL MATERIALS IN THE FIELD." 2025. HTTPS://WWW.CAS.ORG/RESOURCES/CAS-INSIGHTS/AEROGEL-APPLICATIONS
4. PMC. "EXPLORING THE VERSATILITY OF AEROGELS: BROAD APPLICATIONS IN BIOMEDICAL, ENVIRONMENTAL AND ENERGY FIELDS." 2023. HTTPS://WWW.ESPUBLISHER.COM/JOURNALS/ARTICLEDETAILS/1214/
5. AEROGEL.ORG. "CLASSIC AEROGEL PAPERS." ACCESSED SEPTEMBER 2025. HTTPS://PMC.NCBI.NLM.NIH.GOV/ARTICLES/PMC10606714/
6. PMC. "PREPARATION OF SUPER-FLEXIBLE SILICA AEROGEL AND ITS APPLICATION." 2023. HTTPS://WWW.SCIENCEDIRECT.COM/SCIENCE/ARTICLE/PII/S1110016824001790
7. NASA. "AEROGELS: THINNER, LIGHTER, STRONGER." NASA SCIENCE BRIEF, 2023. HTTPS://WWW.NASA.GOV/AERONAUTICS/AEROGELS-THINNER-LIGHTER-STRONGER/
8. RSC PUBLISHING. "VTMS-BASED AEROGEL STRUCTURE PRESERVATION." 2025. HTTP://WWW.AEROGEL.ORG/?P=1196
9. SCIENCEDIRECT TOPICS. "AEROGELS - AN OVERVIEW." ACCESSED SEPTEMBER 2025. HTTPS://PMC.NCBI.NLM.NIH.GOV/ARTICLES/PMC10530858/
10. AEROGEL – AN INNOVATIVE MATERIAL FOR SUSTAINABLE BUILDING! HTTPS://GHARPEDIA.COM/BLOG/AEROGEL-SUSTAINABLE-BUILDING-MATERIAL/