Mechanical and Thermal Characterization of Silane-Treated Basalt/Glass Fiber Reinforced Hybrid Polymer Composites

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Abstract: - The growing demand for strong and cost-effective construction materials has led to increased research on fiber-reinforced polymer composites. Hybridization of fibers is an effective approach to combine the advantages of different materials. In this study, basalt and glass fibers were used as reinforcements in an epoxy matrix to develop hybrid composites. Basalt fibers provide high stiffness and thermal resistance, while glass fibers contribute to cost reduction and improved toughness. To enhance interfacial bonding between fibers and matrix, a silane coupling agent was applied as a surface treatment. Composite laminates were fabricated using the hand lay-up technique with different stacking sequences of treated fibers. Proper surface preparation was carried out to ensure improved adhesion and minimize internal defects. Mechanical properties of the developed composites were evaluated through tensile, flexural, microhardness, and impact tests. The results indicate that silane treatment significantly improves fiber–matrix bonding, enabling efficient stress transfer and reducing internal weaknesses. Hybrid composites exhibited better strength, stiffness, and toughness compared to single-fiber composites. The combination of basalt and glass fibers, along with chemical surface modification, resulted in enhanced mechanical and thermal performance. This study demonstrates that silane-treated hybrid composites are promising materials for load-bearing structural applications due to their improved performance and cost efficiency.

Keywords: Hybrid polymer composites; Basalt fiber; Glass fiber; Silane surface treatment; Mechanical properties

1. Introduction

Lighter, stronger, less expensive building materials are pushing scientists to dig deeper into polymer-based composites. These mixtures often outperform traditional solid substances - offering better rigidity, a favorable balance between strength and mass, resistance to rust, plus steadier behavior under heat. Because they bring so much to the table, such materials now play key roles across aviation, car manufacturing, shipbuilding, and construction projects. Something interesting happens when separate materials team up - composite stuff emerges, built from pieces that keep their own traits. Usually one part wraps around the others - the matrix - it holds things together, passes along stress. Inside it, chunks called reinforcements add toughness andfirmness where needed. That wrapping layer does more than glue; it guides forces through the structure. Different backbones create different classes: some use plastic-like bases, others rely on metals or ceramics. Plastic-based ones show up everywhere since they form easily, cost less, yet still perform well under strain. Each piece plays its role without melting completely into the whole. Glass fibers show up often in plastic-based composite materials thanks to cheap pricing, decent strength, and straightforward manufacturing steps. Still, when jobs require more rigidity or heat resistance, these fibers fall short. From cooled lava rock comes basalt fiber, stepping into view lately as a tougher option - stronger, stiffer, and built to handle temperature swings and harsh chemicals without weakening. Not long ago, few paid much mind to hybrid fiber reinforced composites - now they're turning heads. Mixing basalt with glass fibers inside a polymer base brings stronger results without driving up expense. What stands out is how load spreads more evenly across the material when both fibers work together. Stiffness climbs higher than before thanks to their joint presence. Lasting power gets a quiet boost too, just by pairing these elements under one roof. What really shapes how well fiber reinforced composites work lies in how tightly the fibers bond with the surrounding matrix. When that connection weakens, forces do not move smoothly across layers, which often triggers early breakdown. To strengthen this link, methods like applying silane treatments find frequent use. These coatings plant active chemical sites onto fiber surfaces, helping them mix better with epoxies. As a result, the whole structure handles stress more effectively. One part of this work looked at epoxy mixtures strengthened with basalt and glass fibers coated in silane, made by hand layering. To check how strong they became, samples went through pulling, bending, hitting, and hardness checks. Instead of just adding materials, the focus was on how combining treated fibers changed strength traits. Results came from measuring reactions under stress, showing if these blends could handle real-world loads. Testing aimed not only at numbers but also at seeing where such materials might fit in load-bearing uses.

2. Literature Review

2.1 Hybrid Composites

These days, hybrid polymer composites catch eyes because they mix strength, lightness, and low cost well. One after another, different reinforcing elements get locked into the same plastic base. Because of that setup, useful traits from every ingredient come together smoothly. What results is a material shaped by multiple contributions at once. Most of the time, the base part comes from plastics like cured epoxies, polyesters, or phenolics - sometimes melted types such as nylon or polypropylene instead. Fibers, tiny bits, or needle-like crystals make up the added strengthening stuff. Basalt and glass threads show up often in these roles because they handle force well, resist rust and reactions, plus won't drain your wallet. Blending different reinforcement materials boosts mechanical properties beyond what single-fiber types achieve. Take basalt fibers - strong and stiff - they pair well with glass fibers that bring lower costs and easier handling. Because of how stresses spread across the mix, these combinations tend to resist cracking, handle impacts well, and last longer under repeated loads. The result? A sturdier overall structure without leaning on just one material's traits. Fewer high-priced fibers means savings show up right away when cheaper materials step in without weakening the part. Strength stays good even as costs drop behind the scenes.

2.2Basalt Fibres

From melted basalt rock, a continuous inorganic thread forms when liquid stone gets pushed through tiny holes. This volcanic stone mostly holds minerals like plagioclase, pyroxene, along with olivine mixed inside. Since it comes straight from nature without added chemicals, the fiber counts as a green option for strengthening stuff. Stronger under tension, basalt fibers handle heat well, unlike regular glass ones. Their defense against chemicals stands out too. What helps even more is how they endure alkalis without weakening. Corrosion hardly affects them. Because of this toughness, they fit right into buildings facing tough weather.

2.2.1 Basalt Fibres Production

Starting off, basalt fibers come from carefully selected rock with stable chemistry - these chunks get broken down into smaller pieces and thoroughly washed. Once prepped, they're fed into an electrically heated chamber where heat hits between 1450 and 1550 degrees Celsius, turning stone to liquid. Flowing like syrup, that hot mix gets pushed through fine openings lined with platinum-rhodium alloy, forming unbroken threads. Each strand measures just 10 to 20 micrometers across a fraction of human hair thickness. After shaping, these thin lines go through coating adjustments to improve how they bond later on. Right off, a coating goes on the fibers to cut down wear while boosting how well they mix with plastic-like materials. After that, people gather them into strands or cloths made by weaving - ready for building composites.

2.2.2 Chemical Makeup and Characteristics

Starting off, basalt fibers hold between fifty and fifty-five percent SiO_2, then follow with fourteen to eighteen percent Al_2O_3. Next come ten to twelve percent iron oxides, either Fe_2O_3 or FeO. Calcium oxide shows up next at five to ten percent. Magnesium oxide fills in four to eight percent. Traces of extra oxides appear too, though just barely. Because there's so much silica and alumina, a tough glassy network takes shape inside. That hidden web is why these fibers resist breaking under stress. Fibers made from basalt keep their strength when it gets hot; thanks to a non-crystalline internal layout that spreads stress evenly. Because of this loose atomic arrangement, they stand up well to rust, water intake, and breakdown from chemicals.

2.2.3 Applications

Fiber made from basalt now shows up more often in bridges, car parts, planes, boats, turbines, sports gear - its toughness, ability to resist rust, and steady performance under heat make it a go-to choice. Structures on land or water lean on this material where old options wear down too fast. Even vehicles push forward using these lightweight builds that handle stress without bending easily. Heat does not weaken them like some materials. Out at sea, salty air attacks most metals, yet these composites stay intact. Wind blades spin longer when built with such resilience woven into their shape. On the playing field, equipment lasts through harsh use because of how firmly the fibers hold together. Still, getting basalt fibers to stick well inside a plastic-like base remains tricky because their surfaces resist bonding. So instead of holding tight, fibers sometimes slide out when stress hits, wasting strength. To fix that, people often treat the fiber surface - changing how it connects with its surroundings.

2.3 S-Glass Fibres

Stronger than regular fiberglass, S-glass stands out because it resists stretching better plus handles stress more effectively. Born in labs aiming at aircraft and military gear, its design focuses on staying tough while remaining light. Performance demands in extreme conditions shaped its creation, favoring resilience over basic function.

2.3.1 Chemical Composition

Magnesium aluminosilicate glass makes up most S-glass fibers, usually around 65% SiO_2, alongside 25% Al_2O_3, then roughly 10% MgO. Because of this mix, they handle stress better than regular glass fibers. Heat resistance also turns out stronger under high temperatures.

2.3.2 Manufacturing Process

Starting off, raw ingredients get measured carefully before heading into a blazing hot furnace. Once melted, the molten glass slips through tiny openings in platinum plates, forming thin threads. These strands take shape as they stretch out smoothly behind. A coating gets added along the way - not just any layer, but one that shields while helping glue spread better later. Fibers wind up neatly, either bundled together or woven into cloth. Handling becomes easier because of this treatment. Stronger bonds form when these coated fibers mix with plastics during manufacturing.

2.3.3 Applications

Because they handle stress so well, S-glass fibers show up in aircraft parts, tough sports gear, storage tanks, big windmill wings, also military builds that need toughness above all.

2.4 Basalt Fibre Surface Modification with Silane Coupling Agents

Even when basalt or glass fibers show strong mechanics and heat resistance, their smooth outer layers tend to slip inside plastic bases. Because they do not grip well, force moves unevenly across them failure shows up too soon. One way to deal with this issue is changing the surface. Silane coupling agents often show up in these cases because they work well with many polymers. What makes them stand out is how easily they fit into different setups. Some silane coupling agents carry two different kinds of active sites - one that reacts with inorganic materials another that links to organic polymers - forming bridges across surfaces. One part, called R, links up with the polymer mix through active chemical traits. Meanwhile, OR handles bonding to the fibers surface by joining with its OH spots. These alkoxy pieces break down just enough to form stable connections. Midway through treatment, water breaks down silane into reactive pieces - this latch onto fibers using strong silicon-oxygen links. Because of this bonding shift, treated fibers mix more easily with resins, resist slipping under stress, hold up better when bent or pulled. A steady bond at the meeting point means overall material behaves stronger where it counts. Fiber made from basalt shows real potential - its strength, heat resistance, and low environmental impact stand out. Still, getting it to bond well with plastic-based materials is tough because the connection at the interface tends to fail. Research after research reveals better results when fibers are treated with silane agents; they stick far more effectively to the matrix, lifting the composite's structural capabilities This research aims to create epoxy composite materials using basalt fibers along with S-glass fibers. Its goals include building these hybrid mixes then testing how well they perform. One focus lies in checking strength improvements from combining both fiber types. Another looks at how the blend affects stiffness and resistance under stress. Testing methods will measure physical behavior after fabrication. Analysis follows to compare results across different mix designs. Each step checks whether mixing fibers brings measurable change Starting off with layers of bidirectional basalt and S-glass fibers, fabrication happens manually. The process builds up hybrid composites step by step. Manual placement guides the structure instead of machines. Each layer settles into position one after another. Material alignment follows a specific sequence. Fiber orientations interlock during assembly. This method avoids automated systems entirely. Hand work defines the entire buildup phase. Placement precision depends on steady execution. Laminate thickness grows gradually. Layering continues until complete. Looking into how silane changes the bond where fibers meet the epoxy. With silane applied, the connection point gets a closer look. The way fibers stick to epoxy shifts when silane is used. Silane alters what happens at the meeting line of fiber and resin. Examining the boundary zone after treating fibers with silane. When silane coats fibers, the joint with epoxy behaves differently. Focus lands on adhesion changes triggered by silane exposure. Epoxy grip on fibers transforms post-silane application. Surface tweaks via silane reshape fiber-matrix contact. What occurs between fiber and epoxy evolves under silane influence. Start by making sample materials that follow ASTM rules meant for testing strength. These pieces get built using guidelines tied to how they will be checked for toughness. Each version lines up with set methods so results stay reliable. Building them right means sticking close to what the standards demand. Testing later depends on how well those early steps were done. To check how strong the new composite materials are, tests measure their ability to resist pulling apart. Strength when bent gets examined through flexural testing. Sudden force resistance shows up in impact assessments. Tiny dents reveal hardness at microscopic levels. One way to check if coating fibers changes how strong they are. Checking treated versus untreated mixes shows what works better. Strength differences appear when both kinds face the same tests. Coating may help hold layers together more firmly. Some react differently when pulled apart. Results depend on how materials bond inside. Performance shifts happen after treatment. Not all respond the same under pressure.

3. Materials And Methods

3.1 Materials

In this work, the mix relied on epoxy resin LY556 along with hardener HY951. Known for sticking well to fiber reinforcements, epoxies show up often in composite setups because they resist chemicals. Their toughness stands out. Shrinkage stays low when curing happens. Strength matters too mechanical performance is a key reason these materials get picked. From the start, bidirectional basalt fibre mats paired with E-glass fibre mats at 180 grams per square meter served as reinforcements. What makes basalt stand out is its strong performance under heat, resistance to rusting, along with a better ability to withstand pulling forces when lined up against standard glass fibres. On the flip side, glass fibres made the cut thanks to cheaper pricing, decent strength traits, and simpler handling during production. Starting at around 2000 MPa, basalt fibres can reach up to 4000 MPa in tensile strength, while their stiffness sits between 70 and 120 GPa. Density values fall near 2.65 to 2.8 g/cm^3. On a related note, glass fibres show similar strength levels - spanning 2000 to 3500 MPa with a modulus close to 70 GPa. Before treating the surface, ethanol cleaned away dirt plus old sizing stuff on the fibre mats. The liquid wiped off contaminants so fresh coatings could stick better later. Surface prep needed pure wiping power early in the process. Old residues had to go before anything new got applied. A quick wash with alcohol made sure nothing blocked bonding down the line.

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3.2 Surface treatment of fibres

With the goal of strengthening how well fibres stick to the epoxy, scientists coated the fibres using a silane solution. Before that step, alcohol wiped down the fibre layers, sweeping away oily residues along with leftover coating fragments. Fibres, once cleaned, sat submerged in a mix of water and ethanol laced with silane. Reaction kicked off as the liquid met fibre surfaces, birthing silanol clusters along the way. These clusters linked up through Si–O–Si bridges, hooking onto OH spots already dotting the fibres. With that shift, grip between fibre and matrix tightened - stress moved across the blend more smoothly after. Fibres spent time in warmth once treated, letting silane links finish forming. The heat helped everything settle into place without rushing.

3.3 Fabrication of Hybrid Composites

From start to finish, hybrid composite laminates took shape through the hand lay-up method - a common pick in lab settings because it keeps things straightforward yet adaptable. Right off, someone wiped down the mould before brushing on a release layer so the material wouldn't stick when it set. After that, epoxy and its activator came together at ten parts resin to one part by weight for the base mix. A fresh batch of fibres began the layup basalt set down, then glass, switching back and forth in turn. Before any fabric touched the mould, resin coated the base like morning dew. The mat settled on top without rush. With each new sheet, sticky epoxy soaked into place. Rolling came after, metal pressure smoothing out hidden pockets of air while glue hugged every strand. Fibres stayed drenched, never dry. Fourteen layers made up the laminate, stacked in turn with basalt then glass fibre. Once laid out, the composites sat untouched for a full day at ambient conditions. Only after that did heat treatment begin between eighty and one hundred degrees Celsius - for two or three hours more, locking in the resin's final structure. Out of the mold came the hardened laminates, sliced later into regular test pieces following ASTM rules.

3.4 Composite Sample Composition

A mix of four composite types was created using hand layup technique as shown in figure 1, testing how blending fibers and chemical coating changes performance.

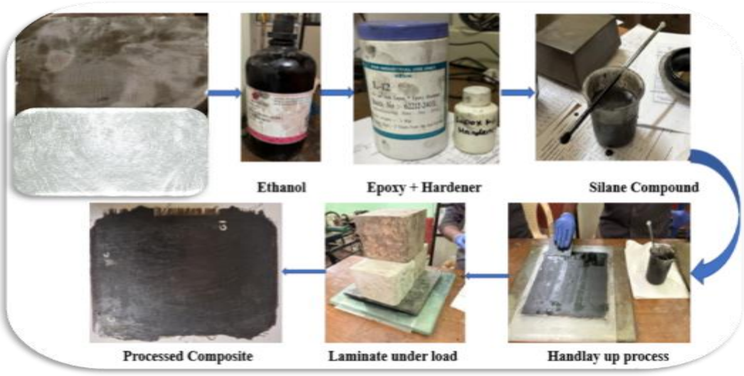

Figure 1: Hand layup process

3.5 Mechanical Testing Microhardness Test

A small force pressed into each sample through a diamond tip, leaving tiny marks. From one test to the next, those dents varied slightly in width. Each measurement followed a standard method meant for fine-scale hardness checks. Instead of relying on just one mark, several were made across the surface. The final number shown came from combining all those separate readings as shown in table 1.

Table 1: Micro hardness testing results

Composite	Microhardness	Avg. Hardness	SD
Basalt Fibres (BF)	23.51	24.67	1.69
	21.49		
	23.82		
	21.69		
Glass Fibres (GF)	25.95	22.62	1.21

	25.91		
	24.51		
	22.34		
Basalt + Glass Fibres (BF+ GF Untreated)	21.75	25.54	1.38
	25.78		
	28.35		
	24.81		
Basalt + Glass Fibres (BF+ GF Silane Treated)	28.86	28.1	0.791
	27.83		
	28.57		
	27.1		

3.6 Tensile Test

From each batch, pieces measuring 165 by 19 by 3 millimeters got cut out for testing. A machine built for stress measurements pulled them apart following rulebook D638. What came next showed how much stretch and pull the material could handle before breaking as shown in table 2.

Table 2: Results of tensile test

Composite	Tensile strength (MPa)	Avg. Tensile strength	SD
Basalt Fibres (BF)	373.23	365.85	7.78
	365.73		
	369.31		
	355.12		
Glass Fibres (GF)	366.39	357.95	6.71
	353.16		
	351.99		
	360.25		
Basalt + Glass Fibres (BF+ GF Untreated)	373.64	382.72	10.4
	385.25		
	396.35		
	375.65		
Basalt + Glass Fibres (BF+ GF Silane Treated)	388.41	387.76	3.76
	391.02		
	382.36		
	389.24		

3.7 Impact Test

Energy absorption during breakage at rapid loading rates is what the experiment checks. Performed per ASTM D256, the method uses a swinging pendulum to hit small notched samples. How much force splits the material gives the toughness value. A machine records the result right after crack begins. Each sample breaks only once under this setup.

Table 3: Results of Impact strengcth

Composite	Impact strength (Joules)	Avg. Impact Strength	SD
Basalt Fibres (BF)	125	126.25	2.75
	128		
	129		
	123		
Glass Fibres (GF)	123	121.75	2.21
	121		
	119		
	124		
Basalt + Glass Fibres (BF+ GF Untreated)	130	131.25	2.75
	134		
	128		
	133		
Basalt + Glass Fibres (BF+ GF Silane Treated)	138	137.1	2.58
	136		
	141		
	134		

Interlaminar Shear Strength A small machine bent samples in three places to check how well layers stick together, following rule D2344. Strength measured this way shows what happens where plies meet.

4. Results And Discussion

Testing how strong the made composite materials are happened using small-scale pressure checks. Strength when pulled apart got measured too. Some tests showed resistance to sudden force. How well layers stick together under stress also went under examination. It turned out the mix of basalt and glass fibres changed how strong the materials were. When basalt was added, things got stiffer and handled heat better. Glass, on the other hand, made them tougher and easier to work with during production. A mix with equal parts basalt and glass fibres each at 30% performed better mechanically than materials using just one fibre type. Stiffness went up thanks to basalt, which also helped carry heavier loads. Toughness and a bit more give came from the glass component instead.From tiny bridges made by silane, fibres stick better to epoxy glue. Those treated held tighter when pulled apart than ones left alone. Because silane grabs onto both sides, force moves more smoothly across layers. Stronger links form where chemistry meets surface. Higher microhardness showed up in silane-treated samples because fibres bonded better with the matrix as shown in figure 2. Crack spread slowed down when fibre layers alternated, which helped hybrid versions handle impacts more easily. One clear takeaway stands out. Mixing fibres along with a silane coating boosts strength in basalt-glass epoxy materials. Performance jumps when these two changes team up. The added treatment reshapes how the material holds up under stress as shown in figure 3. Results show a noticeable shift where toughness gains ground. Instead of working alone, the combo pushes limits further as shown in figure 4. Each piece plays a role when linked through this method. What emerges is stiffer, more resilient composite behaviour. Not just one factor drives change - both steps matter equally. Improvement runs deep, not just on the outside.

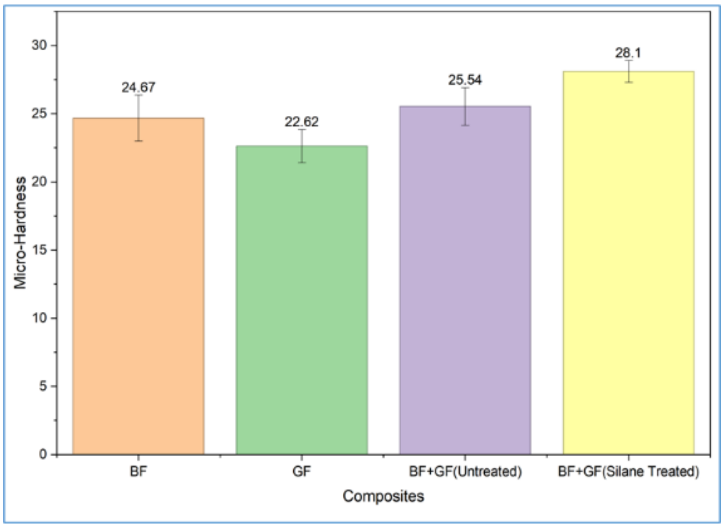

Figure 2: Composite v/s Micro – Hardness

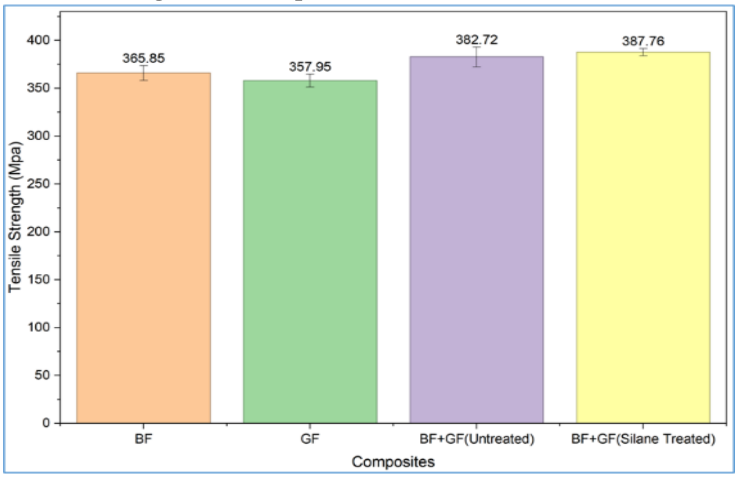

Figure 3: Composite v/s Tensile Strength (Mpa)

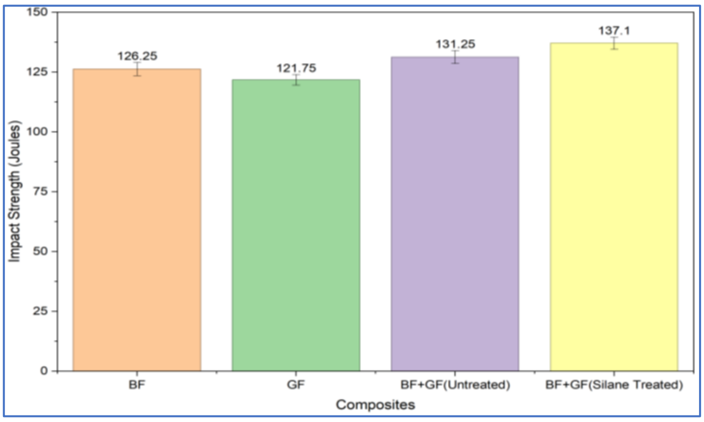

Figure 4: Composite v/s Impact Strength (Joules)

5. Conclusion

A new mix of basalt and glass fibres inside a polymer base took shape through manual layering. With each piece built by hand, strength shifts emerged when fibres joined forces. Surface tweaks using silane changed how parts held up under stress. Tests followed every shift tied to blending styles and outer adjustments. Stiffness jumped when basalt fibers joined the mix, not just stood alone. Glass brought a tougher edge along with cheaper production runs. Performance climbed higher in hybrids than in those built from one fiber type only. Heat resistance tagged along nicely with the sturdier structure. Cost stayed low even as strength went up. From tiny changes on the surface, strength jumped up thanks to a silane coat that helped fibres grip the surrounding material tighter. Because forces moved more smoothly between strands and plastic, things like pull resistance, layer-to-layer hold, and firmness all climbed higher. That smoother push and pull made everything work together much better than before. Fibres made from basalt and glass, when treated with silane, show potential - not through guesswork but testing - as strong yet light materials. Their makeup suits demanding uses where weight matters just as much as strength. Engineering fields might lean on them; so could car design, quietly shifting how parts are built. Results didn't shout success - they simply showed improvement. Not every material change sticks, but this blend holds up under scrutiny. Performance gains come without extra bulk. Testing points toward real-world fit, not just lab curiosity.

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