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An Engineered Blend of Micro-Particles Increases Wellbore Integrity and Enhances Traditional LCM Sealing Capabilities

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Abstract

Drilling through fractured and depleted formations—such as shale and unconsolidated sands—presents persistent challenges, including wellbore instability, whole mud loss, and pressure containment. These issues are intensified by natural and induced fractures, which compromise borehole integrity and hinder circulation and fluid weight management. Traditional wellbore strengthening materials like calcium carbonate, graphitic carbon, and cellulose-based additives have delivered inconsistent results across varying lithologies, often requiring complex multi-product blends and on-site adjustments. To address these limitations, a novel single-sack wellbore strengthening material (SSWSM) was developed, featuring an engineered blend of micro-particles with optimized size, shape, and composition.

The SSWSM is designed to penetrate the formation matrix and fractures, bridging off to increase hoop stress and form a resilient seal capable of withstanding dynamic pressure fluctuations. Its formulation integrates rigid, flexible, deformable, and compressible particles to enhance fluid particle size distribution and sealing effectiveness. Unlike conventional additives, SSWSM simplifies application, eliminates the need for multi-product pills, and requires no modification to solids control equipment—preserving mud properties and improving operational efficiency.

Development of the SSWSM was guided by wellbore strengthening models, mud loss testing, and material evaluations. Laboratory and field results demonstrate that even low concentrations of SSWSM, significantly improve sealing performance and reduce mud loss.

This paper presents a comparative analysis of engineered versus traditional materials, supported by case histories from multiple basins, illustrating improved drilling efficiency, reduced non-productive time, and lower fluid costs.

Introduction

As drilling operations extend into deeper, hotter, and more geologically complex environments, maintaining wellbore integrity has become one of the defining challenges of modern oil and gas development. Many of today’s wells encounter formations with extremely narrow drilling windows, depleted pressures, or natural fractures that make them highly sensitive to changes in mud weight and circulating pressures. In these conditions, even small fluctuations can trigger lost circulation, wellbore instability, or formation breakdown.

Wellbore strengthening has emerged as a critical and effective strategy to address these challenges. By reinforcing the near-wellbore region, operators can safely drill with higher mud weights, reduce fluid losses, and maintain control in zones that would otherwise be difficult or impossible to drill. The technique has evolved from a reactive measure into a proactive engineering practice that supports both operational efficiency and well safety.

The need for wellbore strengthening is closely tied to the changing nature of drilling targets. Many reservoirs being developed today are depleted fields where pore pressure has declined significantly over time. These weakened formations are more prone to fracturing under conventional drilling pressures. At the same time, extended-reach and horizontal wells require higher pump pressures to maintain hole cleaning, which increases the equivalent circulating density at the bottom of the well. Without reinforcement, these pressures can exceed the formation’s fracture gradient.

Naturally fractured formations present another challenge. Pre-existing fractures act as pathways for drilling fluid losses, destabilizing the wellbore and interrupting operations. High-pressure, high-temperature wells add further complexity, as elevated temperatures and stresses reduce the margin for error. In all of these environments, the traditional balance between pore pressure and fracture pressure becomes increasingly difficult to manage, making wellbore strengthening an essential tool for maintaining stability.

Wellbore strengthening encompasses a range of techniques designed to increase the pressure-bearing capacity of the near-wellbore region. The most successful of these methods work by modifying how the formation responds to drilling-induced stresses. A combination of approaches utilizing mechanical bridging, where specially sized materials plug fractures and prevent fluid escape and focus on creating a “stress cage” effect, redistributing stresses around the wellbore so that the formation can tolerate higher pressures have been field proven to be reliable, economic and repeatable.

One common result of wellbore instability is lost circulation. Lost circulation remains one of the most costly and disruptive problems in drilling. When drilling fluid escapes into the formation, it can lead to stuck pipe, well control incidents, cementing failures, or even the loss of the well. Strengthening the wellbore reduces the likelihood of these events by reinforcing the formation before or during drilling.

A major benefit is the expansion of the drilling window. By increasing the effective fracture gradient, wellbore strengthening allows operators to use higher mud weights without inducing fractures. This can eliminate the need for additional casing strings, reduce the number of drilling stages, and improve overall well design flexibility.

Wellbore strengthening also contributes to better wellbore stability. A reinforced near-wellbore region is less prone to collapse, breakout, or washout, which improves hole cleaning, logging quality, and cementing performance. The cumulative effect is a reduction in non-productive time and a more predictable drilling operation.

The economic justification for wellbore strengthening is strong. Lost circulation events can cost millions of dollars in materials, rig time, and remedial operations. Strengthening techniques significantly reduce these risks, often paying for themselves within a single well section. They also enable access to reservoirs that might otherwise be considered too risky or uneconomical to drill. In an industry where operational efficiency and safety are tightly linked, wellbore strengthening has become a foundational practice. It supports more ambitious well designs, reduces uncertainty, and helps ensure that drilling operations remain both safe and economically viable.

Wellbore strengthening is no longer a specialized or optional technique. It has become a core component of modern drilling engineering, driven by the increasing complexity of reservoirs and the need for greater operational reliability. By reinforcing the near-wellbore region, operators can navigate narrow drilling windows, prevent costly fluid losses, and maintain well control in some of the most challenging environments in the industry. As drilling continues to push technical boundaries, the importance of wellbore strengthening will only continue to grow.

Operational Scenarios That Potentially Require Wellbore Strengthening Strategies

Several common drilling scenarios create the conditions in which the formation cannot withstand the pressures imposed by the drilling fluid, making wellbore strengthening essential for maintaining stability and preventing losses. One of the most frequent scenarios occurs when drilling into depleted formations. As reservoirs produce over time, pore pressure declines and the effective stress acting on the rock increases. This shift in the in-situ stress state reduces the minimum horizontal stress, which in turn lowers the fracture initiation pressure. When a well is drilled into such a depleted interval, the weakened formation may no longer support the mud weight required to maintain well control in adjacent higher-pressure zones. The formations above or below the reservoir may still retain their original pore pressures, creating a vertical pressure contrast that narrows the operational drilling window. In such cases, the mud weight needed to prevent influx in the higher-pressure interval may exceed the fracture resistance of the depleted rock. Strengthening the wellbore becomes necessary to safely navigate this imbalance and prevent induced losses.

Another situation arises when the wellbore transitions from a high-pressure interval into a lower-pressure one, a condition commonly referred to as pore pressure regression. These regressions often occur when crossing structural features such as faults or folds, or when entering a new depositional environment with different compaction history. The sudden reduction in pore pressure decreases the formation’s ability to support the existing mud weight, increasing the likelihood of tensile failure and fracture propagation. Without intervention, the mud weight appropriate for the high-pressure zone becomes excessive for the lower-pressure interval. Wellbore strengthening stabilizes the transition zone by increasing the effective fracture pressure, thereby preventing drilling interruptions and maintaining a safe operating margin.

Weak formations at or just below the casing shoe also present a significant challenge. If the casing shoe is set in a mechanically weak interval, formation integrity tests or leak-off tests may reveal fracture gradients lower than required for the next hole section. This limits the allowable mud weight and equivalent circulating density, constraining the drilling program. After drilling ahead with a reduced mud weight to avoid breaking down the weak zone, operators can apply a wellbore strengthening treatment to increase the effective fracture pressure at the shoe. This reinforcement restores operational flexibility and allows the well to safely progress into deeper, potentially higher-pressure formations.

Shale formations introduce a different type of instability. Many shales require elevated mud weights to prevent shear failure, breakout, or time-dependent swelling. However, the mud weight necessary to stabilize the shale may exceed the fracture resistance of the formations above. This creates a conflict between maintaining wellbore stability in the shale and avoiding induced losses in the overlying weaker rocks. Strengthening the upper formations increases their fracture resistance, enabling the operator to use the mud weight required for shale stability without compromising the integrity of the overburden.

Abnormal pressure intervals can also drive the need for wellbore strengthening. When drilling into over-pressured formations—such as sands influenced by nearby injection wells, compaction disequilibrium, or hydrocarbon generation—the mud weight must be increased to maintain well control. However, the formations above the over-pressured zone may not be able to tolerate the higher wellbore pressure. This creates an extremely narrow operational window, particularly in deep or high-temperature environments. Strengthening the upper intervals increases their fracture initiation pressure, ensuring that the well can safely accommodate the increased mud weight without inducing losses.

Finally, wellbore strengthening is valuable in situations where losses are triggered not by static mud weight but by transient surge pressures. Surge-induced losses often occur in wells with narrow annular clearances, where running casing, tripping pipe, applying high pump rates, or even coming off the slips too abruptly can momentarily elevate bottom-hole pressure beyond the formation's fracture limit. These short-duration pressure spikes can initiate fractures even when the static mud weight is within the safe window. In wells with a history of such events, strengthening the wellbore provides an additional margin of safety and reduces the likelihood of pressure-induced losses during routine operations.

Together, these scenarios illustrate why wellbore strengthening has become a vital tool in modern drilling. Whether the challenge involves depleted formations, pressure transitions, weak casing-shoe intervals, shale stability conflicts, abnormal pressures, or surge-related events, strengthening techniques provide the additional support needed to maintain wellbore integrity and ensure safe, efficient drilling.

Targeted Formation Types

Wellbore strengthening is applied most effectively in rock types where the in-situ stress state, pore-pressure conditions, and mechanical properties combine to produce a low fracture initiation pressure (FIP) or a narrow operational drilling margin. These rocks typically exhibit low tensile strength, reduced effective stress support, high natural fracture density, or significant heterogeneity in elastic and strength parameters. The following rock types represent the primary targets for strengthening treatments due to their geomechanical behavior and failure tendencies under drilling-induced stresses.

Depleted Sandstones

Depleted sandstones are among the most critical targets because reservoir depletion alters the effective stress regime. As pore pressure declines, the horizontal stresses do not fully rebound, resulting in a reduced minimum horizontal stress (Shmin). Since fracture initiation pressure is strongly controlled by Shmin, depleted sandstones often exhibit significantly lower fracture gradients than adjacent formations. The rock matrix may remain competent, but the stress path during depletion (often trending toward a uniaxial strain response) leads to a mechanically weakened near-wellbore environment. Strengthening treatments are used to artificially elevate the FIP by creating a stress cage or by bridging microfractures that would otherwise propagate under modest wellbore pressure increases.

Unconsolidated and Poorly Consolidated Sands

These sands have minimal cementation and extremely low tensile strength, often approaching zero. Their cohesionless nature means that the effective stress required to initiate tensile failure is low, and the fracture toughness of the formation is minimal. Under drilling conditions, these sands fail through a combination of tensile parting and granular dilation. Because they lack structural integrity, they are highly susceptible to lost circulation when exposed to elevated equivalent circulating densities (ECDs). Strengthening in these intervals focuses on forming a mechanically competent bridging network that increases the apparent fracture resistance and reduces the permeability of incipient failure planes.

Naturally Fractured Carbonates

Carbonate formations frequently contain pre-existing discontinuities such as open fractures, stylolites, vugs, and karstic voids. Even when the carbonate matrix exhibits high compressive strength and elastic stiffness, these discontinuities dominate the mechanical response. The presence of open or partially open fractures reduces the effective fracture gradient because the wellbore pressure required to propagate an existing fracture is significantly lower than that required to initiate a new one. Strengthening treatments in carbonates aim to plug or choke these features, increasing the pressure required to reopen or extend them. The stress cage mechanism is particularly effective in these rocks because fracture apertures can be mechanically bridged with appropriately sized materials.

Weak or Rubble-Prone Carbonates (e.g., Chalks, Soft Limestones)

Chalks and highly weathered limestones exhibit low unconfined compressive strength (UCS), low Young's modulus, and high porosity. Their mechanical behavior is dominated by pore collapse, grain crushing, and ductile deformation under stress. These rocks often fail at pressures well below the expected fracture gradient due to their low tensile strength and tendency to undergo shear-enhanced compaction. Strengthening treatments help stabilize the near-wellbore region by reducing stress concentration at the borehole wall and by forming a mechanically supportive barrier that limits deformation.

Mechanically Unstable Shales

Shales are not typically weak in terms of fracture gradient, but they often require elevated mud weights to prevent shear failure, breakout, or time-dependent swelling. The challenge arises when the formations above the shale cannot tolerate the mud weight required for shale stability. In these cases, strengthening is applied to the overlying weaker rocks—often sands or carbonates—so that the mud weight can be increased without inducing losses. The strengthening treatment effectively raises the operational pressure window, allowing the well to maintain the mud weight needed to prevent shale instability.

Interbedded Formations with High Mechanical Contrast

Stratigraphic sequences that alternate between strong and weak layers—such as sandstone–shale or carbonate–shale packages—create abrupt changes in elastic moduli, UCS, and tensile strength. When drilling through these sequences, the mud weight required to maintain stability in the stronger units may exceed the fracture resistance of the weaker ones. The weaker layers become the limiting factor in the drilling margin. Strengthening these intervals increases their fracture resistance and allows the operator to maintain a consistent mud weight across the entire section without inducing losses.

Over-Pressured Sands Beneath Weak Overburden

When drilling into over-pressured sands, the mud weight must be increased to maintain well control. However, the overburden—often composed of weak shales or unconsolidated sands—may not be able to withstand the increased wellbore pressure. The mechanical contrast between the over-pressured target and the weak overburden creates a narrow operational window. Strengthening the overburden increases its FIP, enabling safe entry into the high-pressure interval without inducing losses above.

Low Fracture Gradient Rocks Prone to Surge-Induced Failures

Any rock type with a low fracture gradient—regardless of lithology—can become a target when the well is susceptible to transient pressure spikes. Surge pressures generated during casing running, pipe tripping, high pump rates, or abrupt operational changes can momentarily exceed the formation's fracture resistance. These short-duration events can initiate fractures even when static mud weight is within the safe window. Strengthening increases the formation's tolerance to dynamic pressure excursions, reducing the risk of induced losses.

Particle Type and Size Selection

Particle type and size selection for wellbore strengthening is fundamentally a geomechanical design process that requires understanding how particles interact with fractures under downhole stress conditions. The objective is not simply to plug a void but to create a mechanically competent structure within the fracture that can resist reopening, support elevated wellbore pressures, and modify the near-wellbore stress field. Achieving this requires careful engineering of particle size distribution, particle rigidity, deformability, and compatibility with the drilling fluid system.

The starting point for particle selection is an estimation of the target fracture geometry. Fracture width at the wellbore is controlled by the minimum horizontal stress, the elastic properties of the rock, and the pressure differential between the wellbore and the formation. In depleted formations or naturally fractured intervals, fracture apertures may be larger and more irregular, while induced fractures in competent formations tend to be narrower and more uniform. The median particle size must be selected so that particles can enter the fracture but are large enough to form a stable bridge. In practice, this means the median particle diameter is typically engineered to be roughly one-third of the estimated fracture width, allowing the particles to lodge at the fracture throat and initiate the bridging process.

Once the bridging particles are selected, the particle-size distribution becomes the dominant factor in determining the mechanical strength of the plug. A single particle size cannot form a stable structure; instead, a graded distribution is required to achieve dense packing. Coarser particles form the primary load-bearing skeleton, while progressively smaller particles fill the interstitial voids and reduce permeability. This hierarchical packing structure increases the stiffness of the plug and its resistance to shear displacement or tensile reopening. The resulting composite behaves as a mechanically reinforced zone that elevates the fracture initiation pressure and fracture propagation pressure, enabling the wellbore to tolerate higher mud weights and ECDs.

Particle type selection is equally important. Rigid particles such as calcium carbonate, ground marble, silica sand, ceramic beads, and graphite are used when the goal is to create a strong, load-bearing bridge capable of resisting high differential pressures. These materials maintain their shape under compressive stress and are particularly effective in induced fractures or in formations where the fracture geometry is relatively stable. In contrast, deformable or resilient particles—such as elastomeric beads, resilient graphitic materials, or rubber particles—are used when fractures are irregular, tortuous, or prone to dilation. Their ability to deform allows them to wedge into variable apertures and maintain contact with the fracture walls even under fluctuating pressures.

Sealants, such as flake materials, are incorporated to reduce the permeability of the plug and prevent fluid leak-off. These materials penetrate microfractures and pore throats that more rigid particles cannot access, creating a low-permeability barrier that enhances the overall integrity of the strengthening structure. In formations with micro-fractured matrices or high intrinsic permeability, these fine materials are essential for achieving a complete seal.

The concentration of particles in the fluid must be sufficient to ensure that successful bridging occurs, but not so high that it compromises pumpability or induces excessive ECD. Preventive, or proactive, strengthening typically uses lower concentrations to maintain fluid rheology, while reactive treatments necessitate the of use much higher concentrations to rapidly form a plug within an active fracture.

In summary, particle type and size selection for wellbore strengthening is a highly engineered process that integrates fracture mechanics, particle packing theory, material science, and drilling fluid rheology. The most effective strengthening treatments rely on a carefully designed blend of rigid and deformable particles with a graded size distribution that can bridge, pack, and seal fractures while withstanding the mechanical loads imposed by drilling operations. This engineered approach enables operators to increase the fracture resistance of the near-wellbore region, expand the operational drilling window, and reduce the risk of lost circulation in challenging formations.

Product Development and Design

To satisfy all the varying conditions dictated above, a Single Sack Wellbore Strengthening Material (SSWSM) presented a field solution that could attack the varying wellbore conditions and still be applicable and economical. The SSWSM was developed as an engineered wellbore-strengthening system grounded in geomechanics, fracture mechanics, and particle-packing theory. Its design objective was to provide a predictable and repeatable method for increasing both the fracture initiation pressure (FIP) and fracture propagation pressure (FPP) by modifying the near-wellbore stress environment. Unlike conventional lost-circulation materials, which rely primarily on bulk plugging behavior, SSWSM was formulated as a purpose-built strengthening technology with controlled particle architecture, engineered deformability, and an optimized particle-size distribution.

A central design principle of the SSWSM is fracture-mechanical bridging. The system delivers a blend of rigid and deformable particles into the near-wellbore fracture network, where they form a mechanically competent bridge at the fracture throat. This bridging structure is engineered not only to seal the fracture but also to alter the local stress field. Once the fracture is packed with the SSWSM blend, the particle network generates a stress-cage effect that increases the hoop stress surrounding the wellbore. This redistribution of stresses elevates the pressure required to reopen or propagate the fracture, thereby expanding the operational drilling window and improving wellbore stability.

The particle-size distribution (PSD) used in SSWSM was developed through particle-packing models rather than empirical blending. The formulation incorporates a graded distribution of appropriately sized particles designed to enter the fracture, establish a stable arch, and progressively fill the internal void space. Relatively larger particles form the primary load-bearing skeleton, while relatively medium and finer particles occupy the interstitial spaces, creating a dense, low-permeability structure. This engineered packing arrangement enhances the stiffness and mechanical integrity of the plug, enabling it to withstand high differential pressures and resist shear displacement or tensile reopening.

Particle type selection was equally critical to the system's performance and field applicability. The SSWSM incorporates rigid particles with high compressive strength to maintain structural integrity under elevated downhole stresses, combined with deformable particles capable of conforming to irregular fracture geometries and maintaining contact under fluctuating pressures. This hybrid approach allows the system to perform effectively in both induced and naturally fractured formations. The deformable components also provide resilience against surge-induced pressure spikes, reducing the likelihood of transient fracture reopening becoming an operational issue.

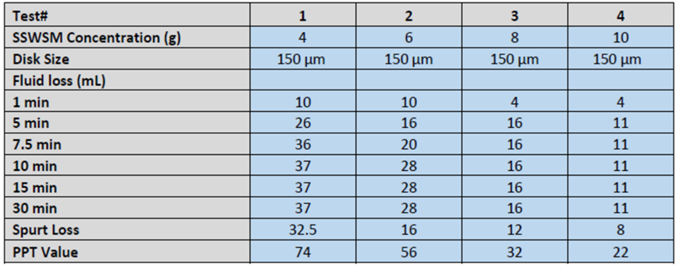
Chemical and thermal stability were key design considerations. SSWSM was formulated to remain stable in both water-based and oil-based drilling fluids, maintain suspension without adversely affecting rheology, and tolerate high-temperature environments. Material selection focused on preventing degradation, swelling, or dissolution under downhole conditions, ensuring long-term stability of the strengthening structure.

The development of SSWSM included extensive laboratory evaluation using fracture-slot testing, dynamic leak-off testing, and permeability-plugging assessments to quantify its ability to increase FIP and FPP. Geomechanical modeling, including stress-cage simulations, was used to evaluate how the particle plug modifies the near-wellbore stress field and to optimize the formulation for maximum strengthening efficiency. These combined laboratory and modeling efforts provided a rigorous basis for the system's design and validated its performance across a range of formation types and operational conditions.

Testing was conducted to evaluate the sealing performance of an engineered SSWSM in a 12.7 ppg diesel-oil-based drilling fluid using a 150-micron ceramic disk as the test medium. The following procedure was used to prepare and evaluate the samples.

1. A 350-mL volume of 12.7 ppg diesel-oil-based mud was placed in a metallic mixing cup and conditioned on a Hamilton Beach mixer for 30 minutes at a high shear rate.
2. The required concentration of SSWSM., as specified in Table 1, was added to each mud sample and mixed for an additional 5 minutes to ensure uniform dispersion.
3. Each treated sample was then transferred to an OFITE Permeability Plugging Tester (PPT) equipped with a 150-micron ceramic disk serving as the filtration medium.
4. After loading the samples into the PPT cells, the apparatus was heated to a test temperature of 120°F.
5. Once the target temperature was reached, a differential pressure of 3,000 psi was applied, and the resulting fluid loss was measured.

The results obtained from this testing program are summarized in the following table.



Test#	1	2	3	4
SSWSM Concentration (g)	4	6	8	10
Disk Size	150 µm	150 µm	150 µm	150 µm
Fluid loss (mL)				
1 min	10	10	4	4
5 min	26	16	16	11
7.5 min	36	20	16	11
10 min	37	28	16	11
15 min	37	28	16	11
30 min	37	28	16	11
Spurt Loss	32.5	16	12	8
PPT Value	74	56	32	22

Table 1 – SSWSM PPT Testing Results

In summary, SSWSM was engineered as a comprehensive wellbore-strengthening system rather than a collection of lost-circulation materials. Its formulation integrates controlled particle architecture, engineered deformability, optimized PSD, and geomechanical modeling to deliver predictable and measurable increases in fracture resistance. This design enables operators to expand the drilling window, stabilize weak or depleted formations, and mitigate both static and surge-induced losses in complex wellbore environments.

Field Applications

In wellbore strengthening, the distinction between a proactive and a reactive approach lies primarily in the timing of the intervention and the geomechanical intent behind it. A proactive approach is implemented before any indication of wellbore instability or fluid losses is observed. Its purpose is to increase the fracture resistance of the formation in advance, thereby expanding the operational drilling window and preventing instability from occurring. In this strategy, strengthening materials are incorporated into the drilling fluid or periodically introduced while drilling through intervals known to have narrow drilling margins, depleted pressures, weak casing-shoe integrity, or high sensitivity to surge pressures. By placing strengthening materials into the near-wellbore region before the formation is exposed to critical pressures, the proactive method aims to elevate the fracture initiation pressure and reduce the likelihood of induced fractures during drilling, circulation, or tripping operations. In essence, proactive strengthening is a preventive geomechanical measure designed to maintain wellbore integrity ahead of potential failure.

A reactive approach, in contrast, is applied only after the formation has already failed, typically evidenced by partial or total lost circulation. In this case, the objective is to seal an active fracture and restore the wellbore's pressure-bearing capacity. Reactive strengthening relies on high-concentration pills or specialized slurries capable of rapidly bridging and plugging an existing fracture under dynamic flow conditions. Because the fracture is already open and may be propagating, the materials used in reactive treatments must be capable of forming a mechanically competent plug that can withstand the applied differential pressure and reestablish a stable near-wellbore stress environment. Once the fracture is sealed, the mud weight can be increased back to operational levels, allowing drilling to resume safely.

The fundamental difference between the two approaches is therefore one of intent and timing. Proactive strengthening seeks to prevent instability by reinforcing the formation before it is exposed to critical pressures, whereas reactive strengthening seeks to correct instability after it has occurred. Both approaches play important roles in modern drilling operations, but proactive strengthening generally provides greater operational reliability, reduces nonproductive time, and minimizes the risk of severe lost-circulation events.

One of the key advantages of the engineered SSWSM system is its carefully designed particle-size distribution, which results in more than 60% material retention on API 170-mesh shaker screens. This retention characteristic allows the system concentration to be maintained in a proactive application or rapidly built in a reactive application without the need to switch to coarser screens. Maintaining standard screen configurations improves drilled-solids removal and enhances overall solids-control efficiency. In addition, the reduced solids loading minimizes both surface and downhole tool wear, lowers dilution requirements, and contributes to more stable and manageable drilling-fluid rheologies.

Reactive Applications

Reactive Field Application 1 - A Permian Basin operator addressing significant mud losses while drilling the Clear Fork and Upper Sprayberry formations. These formations, characterized by low frac gradients, posed challenges such as excessive mud losses, limited casing running speeds, and difficulties maintaining returns during cementing. SSWSM was applied to mitigate these issues. The solution resulted in zero measurable mud losses, improved hole stability, successful casing runs, and full returns during cementing, saving an estimated $90,000 per well.

The treatment plan included:

- 30 bbl sweeps with 25 ppb of SSWSM.
- Continuous addition of 5 sacks per hour to the active system. The regimen began upon observing losses and continued through the Upper Sprayberry formation, transitioning to only the 5 sacks/hour addition until interval total depth (TD).

The implementation of SSWSM yielded the following outcomes:

- No measurable mud losses during the interval.
- Improved hole stability.
- Successful casing runs without excessive losses.
- Full returns during cementing operations.
- Estimated cost savings of $90,000 per well.

Reactive Field Application 2 - SSWSM was utilized to address significant wellbore instability encountered while drilling through the Dakota formation. The instability could not be mitigated by increasing mud weight due to fluid losses in the Mission Canyon group at 11.0 ppg, which constrained pressure management options.

The SSWSM was applied through a sweep regime of 15 ppb SSWSM and 15 ppb asphalt, supplemented with 6 sacks per hour added to the active system. This treatment successfully increased mud weight from 11.0 to 12.0 ppg without fluid losses. At casing point, two pills were spotted:

- 10 ppb SSWSM / 20 ppb conventional LCM across the Mission Canyon
- 15 ppb SSWSM / 15 ppb asphalt across the Dakota section

The drill string was pulled without incident, casing was run to the bottom, and the cement job was completed with full returns. The treatment saved significant time and costs, with the Drilling Consultant concluding the SSWSM application being "worth its weight in gold."

Reactive Field Application 3 - While drilling the curve section (~80° inclination) of a Wolfcamp B well in Culberson County, Texas, the operator experienced severe lost circulation, with losses ranging from 60–70 bbl/hr of oil-based mud (OBM) over the interval from 12,355 ft to 21,300 ft MD. The operation was being in a 7-7/8 in. hole size with an 11.0 ppg OBM system.

To mitigate losses, SSWSM, was applied. The treatment strategy consisted of 30 ppb SSWSM sweeps combined with a progressive increase in background concentration, which was maintained while drilling ahead through the curve and lateral sections. SSWSM was selected for its high retention at the shakers and suitability for continuous background treatment without adversely impacting solids-control efficiency.

Following implementation, lost circulation rates were significantly reduced once the material reached the thief zone. Average losses decreased to approximately 14 bbl/hr over a 24-hour period, with stable fluid performance observed through total depth. The reduction in OBM losses translated to estimated cost savings exceeding $100,000 per day, demonstrating the effectiveness of SSWSM as a cost-effective wellbore-strengthening solution in fractured and depletion prone Wolfcamp intervals.

Reactive Field Application 4 - During drilling of the lateral section of a Permian Basin Barnett Shale well, the operator experienced persistent wellbore instability manifested by repeated hole collapses. Attempts to increase mud weight to stabilize the formation consistently resulted in immediate fluid losses, preventing effective pressure management and hindering drilling progress.

To expand the mud-weight operating window, a SSWSM wellbore strengthening strategy was selected. Prior to the SWSSM application, the rig was forced to trip out for a clean-out assembly, and severe instability required back-reaming every stand through the curve and reaming to bottom on the return trip. Multiple near-stuck-pipe events highlighted the need for immediate strengthening intervention. After returning to bottom, two 75-bbl sweeps of 60 ppb SSWSM were pumped, supplemented by continuous additions of one sack every ten minutes to the active system. After circulating the sweeps to surface, the equivalent mud weight was increased from 11.2 to 12.2 ppg without any associated losses.

Following treatment, the work string was pulled without back-reaming, casing was run smoothly, and the cement job was completed with full returns. The operation demonstrated that SSWSM effectively stabilized the lateral interval and enabled a 1.0-ppg increase in mud weight while maintaining wellbore integrity.

Proactive Applications

Proactive Field Application 1 - A narrow pressure window between the Dakota and Greenhorn formations created a significant drilling challenge, as the mud weight required to control the Dakota risked exceeding the fracture gradient of the underlying Greenhorn. To safely expand the operational window, the operator deployed an engineered SSWSM wellbore-strengthening system. The SSWSM material was applied through 10-bbl sweeps at 20 ppb, supplemented with continuous additions to the active system. This treatment enabled the mud weight to be increased to 13.0 ppg without inducing losses, effectively controlling water influx from the Dakota while maintaining Greenhorn integrity. The interval was drilled without instability or nonproductive time, demonstrating the system's ability to proactively reinforce the near-wellbore region and mitigate fracture-related risks. The field application further confirmed the consistency and repeatability of SSWSM across varying drilling environments and highlighted the value of specialist-guided treatment design.

Proactive Field Application 2 - A Williston Basin operator drilling in the Indian Hills region of the Bakken encountered persistent wellbore-stability challenges in the Mission Canyon and Dakota formations, both of which are weakened by depletion and an extensive natural fracture network. Historical performance on offset wells showed average losses of approximately 400 bbl of oil-based mud (OBM) despite the use of a graphitic-carbon LCM. Additional operational constraints included limited casing-run speeds of 30–40 ft/min and an inability to maintain full returns during cementing.

To address these issues, a SSWSM was selected. As the well approached the problematic intervals, the operator implemented a structured sweep program consisting of 10-bbl sweeps at 20 ppb. Owing to the engineered particle-size distribution, more than 60% of the material was retained on the rig's API 170 screens, enabling the system concentration to build effectively. Prior to running casing, two high-concentration SSWSM pills were spotted in the open hole: a 40-bbl, 40-ppb pill across the Mission Canyon and a 90-bbl, 40-ppb pill across the Dakota.

The strengthening treatment reduced total mud losses from the historical 400-bbl average to fewer than 100 bbl, including during casing operations. Improved wellbore stability also allowed casing-run speeds to increase to 80–90 ft/min. Total savings for the interval were estimated at $88,000 in fluid costs and $17,800 in rig time. Full returns were maintained throughout the cement job, improving the likelihood of achieving effective zonal isolation

Proactive Field Application 3 - During drilling of the intermediate section of a Haynesville well, the operator experienced severe and persistent mud losses ranging from 30 to 80 bbl/hr. Multiple lost-circulation and wellbore-strengthening treatments were deployed without success. As drilling continued toward the planned total depth, the wellbore ultimately collapsed, resulting in a stuck drill string and a twist-off. After several unsuccessful fishing attempts, the interval was deemed unrecoverable, and the operator was forced to abandon the section and initiate a re-drill.

For the re-drill, the operator elected to pursue a more robust wellbore-strengthening strategy centered around a SSWSM. Unlike conventional approaches that primarily form a surface-level barrier, the goal was for SSWSM to penetrate the near-wellbore fracture network and create a durable internal stress cage. Thereby increasing local hoop stress, reinforcing the near-wellbore region, and reducing the likelihood of induced fracture propagation.

After drilling through the anhydrite interval, the operator incorporated a background concentration of 15 ppb SSWSM into the active mud system and maintained this concentration through the remainder of the section. The interval was drilled successfully with only minor seepage losses observed. Intermediate casing was run without incident and cemented with full returns, marking a successful completion of the previously problematic interval.

Proactive Field Application 4 - An operator drilling an intermediate interval in the Haynesville Shale faced a high-risk environment characterized by severe historical fluid losses, with offset wells in the area reporting more than 5,000 bbl of lost mud in this section alone. To address the operational and economic risks associated with such losses, the operator engaged DrillChem to provide a more effective wellbore-strengthening strategy.

At a depth of 6,000 ft, the operator introduced SSWSM at a background concentration of 15 ppb and maintained this concentration through the remainder of the interval to total depth at 12,607 ft. The historically problematic Hosston formation was drilled with only minor seepage losses, totaling approximately 60 bbl. Across the entire interval, cumulative losses remained below 100 bbl, representing a substantial improvement compared with offset performance.

The strengthened wellbore also enabled the operator to increase mud weight to 11.6 ppg to better manage gas-related challenges, whereas previous wells were limited to 11.2 ppg due to severe losses. Casing was run with minimal seepage, and the intermediate cement job was completed with full returns, demonstrating the effectiveness of the SSWSM treatment in stabilizing the interval and mitigating extreme fluid losses.

Proactive Field Application 5 - A Williston Basin operator drilling in the Blue Buttes and Buffalo Wallow regions of the Bakken faced persistent wellbore-stability challenges in the Mission Canyon and Dakota formations, both of which are weakened by depletion and an extensive natural fracture network. Offset wells routinely experienced 400–600 bbl of OBM losses while relying on a combination of graphitic-carbon and fiber-based LCMs. Additional operational constraints included limited casing-run speeds of 30–40 ft/min and an inability to maintain full returns during cementing.

A SSWSM application was selected which consisted of 20-bbl sweeps at 30 ppb pumped throughout the interval, supplemented by a 30-ppb SSWSM pill spotted across the Dakota group prior to pulling out of hole to run casing.

Across eight wells treated with this approach, the operator observed a 300–500 bbl reduction in mud losses per well, full returns during cementing, and elimination of the need for frac strings or remedial cement. Casing-run speeds improved by 3–6 hours per well, with no losses encountered while running casing. No additional LCMs or strengthening materials were required beyond SSWSM, and the operator subsequently adopted the system as the standard operating procedure for this interval.

The operator reported average savings of $140,000 per well, demonstrating the consistent and repeatable value of the SSWSM strengthening strategy in this region.

Conclusions

This paper demonstrates that effective wellbore strengthening requires a fundamentally different design philosophy than conventional lost-circulation mitigation. Rather than relying on empirical bulk plugging behavior, wellbore strengthening must be approached as a geomechanical problem in which the objective is to modify the near-wellbore stress state and increase both fracture initiation pressure (FIP) and fracture propagation pressure (FPP). The results presented in this paper show that an engineered particle system, designed using fracture mechanics and particle-packing principles, can deliver consistent and repeatable strengthening across a wide range of lithologies and operational scenarios.

Laboratory evaluations confirmed that the Single-Sack Wellbore Strengthening Material (SSWSM) forms a mechanically competent structure capable of withstanding high differential pressures. Permeability plugging testing conducted at 3,000 psi demonstrated that the engineered particle-size distribution rapidly establishes a stable bridge and develops a low-permeability seal, even in micron-scale fracture analogs. The graded particle architecture enables dense internal packing, where coarse particles form the primary load-bearing framework and finer particles progressively reduce void space and leak-off pathways. This internal structure increases plug stiffness and resistance to shear displacement and tensile reopening, which are the dominant failure mechanisms under drilling-induced stress cycling.

The integration of rigid and deformable particle types proved critical to performance. Rigid components provide structural integrity under compressive stress, while deformable and resilient particles accommodate irregular fracture geometries and maintain contact under fluctuating wellbore pressures. This hybrid mechanical response allows the SSWSM system to perform effectively in both induced fractures within competent formations and naturally fractured or depleted intervals where fracture apertures are variable and stress conditions are evolving. The combined effect supports the development of a stress-cage mechanism that redistributes hoop stress around the wellbore, thereby increasing the effective fracture resistance of the near-wellbore region.

Field applications validate the laboratory findings and demonstrate scalability across different basins, drilling environments, and operating strategies. In reactive applications, SSWSM rapidly reduced or eliminated active fluid losses, restored pressure-bearing capacity, and enabled increases in mud weight without compromising wellbore stability. In several cases, the system allowed drilling to continue through intervals that had historically resulted in severe losses, stuck pipe, or premature casing points. These outcomes indicate that the engineered plug not only sealed existing fractures but also resisted further propagation under sustained equivalent circulating densities.

Proactive applications further highlight the value of treating wellbore strengthening as a preventive geomechanical intervention. By introducing SSWSM ahead of anticipated weak or depleted intervals, operators were able to expand the operational drilling window, tolerate higher mud weights, and reduce sensitivity to surge-induced pressure excursions. The system consistently improved casing-running performance and enabled full-returns cementing in formations with a long history of partial or total losses. These results demonstrate that elevating fracture resistance in advance is more reliable and economical than relying on reactive treatments alone.

An important operational outcome of this study is the demonstrated compatibility of SSWSM with standard solids-control practices. More than 60% retention on API 170-mesh shaker screens allows concentrations to be built and maintained without screen changes or excessive dilution. This characteristic preserves drilled-solids removal efficiency, minimizes rheological instability, and reduces surface and downhole equipment wear. As a result, SSWSM can be applied continuously as a background strengthening agent or at high concentrations for reactive treatment without introducing secondary operational risks.

Collectively, the laboratory data and field results confirm that an engineered, single-product wellbore strengthening material can deliver measurable increases in fracture resistance while simplifying execution at the rig site. By shifting from empirically blended lost-circulation materials to a system designed around fracture geometry, particle packing, and stress redistribution, operators can achieve more predictable outcomes, reduce non-productive time, and lower overall fluid-related costs. The SSWSM system provides a repeatable and scalable solution for strengthening weak, fractured, and depletion-prone formations and represents a practical advancement in the application of geomechanics to modern drilling operations.

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Nomenclature

BHA = Bottomhole Assembly
SSWSM = Single Sack Wellbore Strengthening Material
FIP = Fracture Initiation Pressure
FPP = Fracture Propagation Pressure
ECD = Equivalent Circulating Density
UCS = Unconfined Compressive Strength
PSD = Particle Size Distribution
PPG = Pounds per Gallon
PPB = Pounds per Barrel
EMW = Equivalent Mud Weight
PPT = Particle Plugging Test
PSI = Pounds per Square Inch
API = American Petroleum Institute
LCM = Lost Circulation Material
TD = Total Depth
OBM = Oil Based Mud
WBM = Water Based Mud