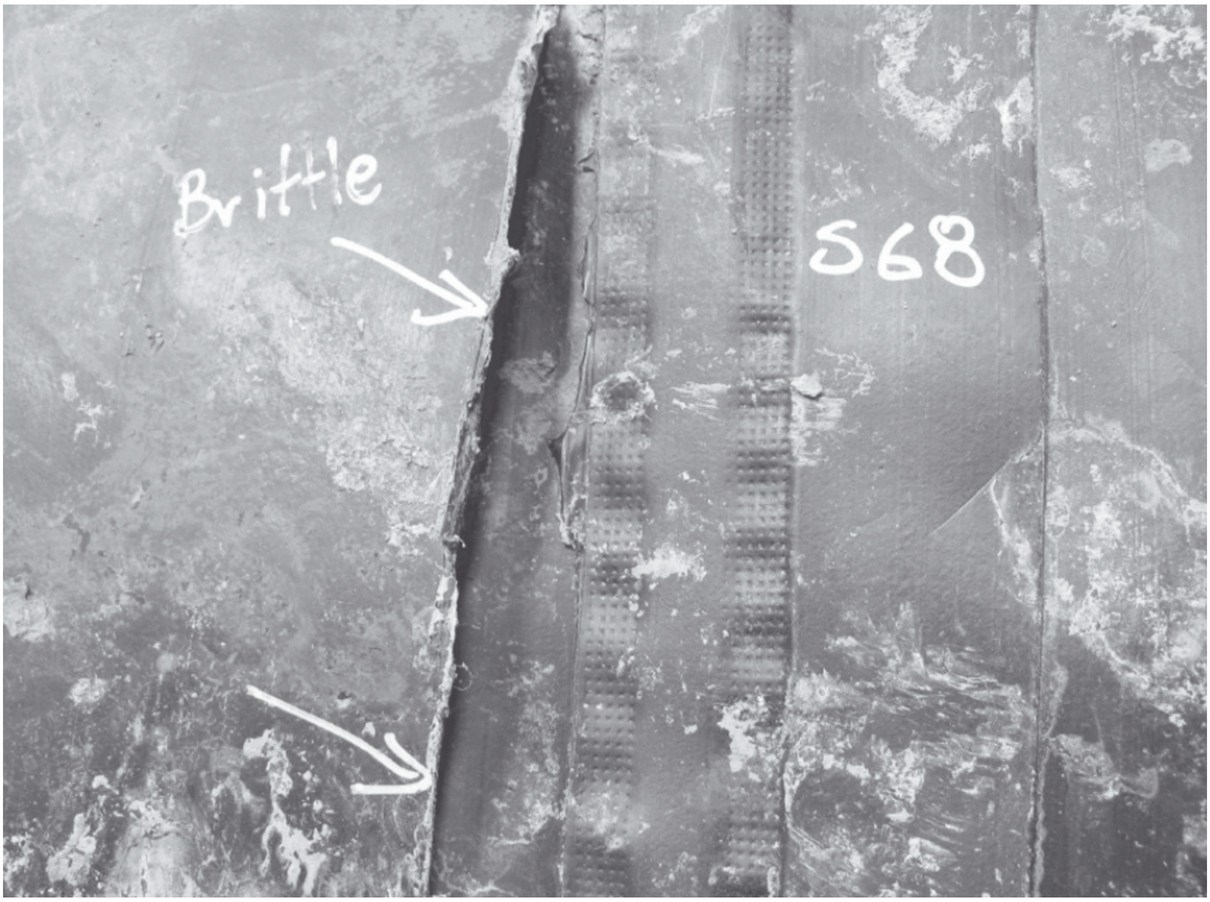
Brittle HDPE Geomembrane Welds Despite High OIT: Causes and Prevention

by Ben Lewis (GeoKonect) and John Scheirs (ExcelPlas)



Stress Crack Resistance (SCR) – Key to Weld Ductility and Durability

High-density polyethylene (HDPE) geomembranes can exhibit brittle weld failures even when oxidation induction time (OIT) values are high. The primary reason is that Stress Crack Resistance (SCR), not just antioxidant content, governs long-term ductility. Experts consider SCR *"the most important mechanical durability parameter"* for HDPE geomembranes. While different HDPE resins often have similar tensile strength and elongation, their SCR can

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differ by two orders of magnitude (10×) due to resin design. A geomembrane with low SCR is prone to slow crack growth under sustained stress, leading to brittle, glass-like fractures, even if it initially meets short-term strength specs. In contrast, a high-SCR material resists slow cracking and maintains weld integrity over time. Field experience has shown that liners exceeding standard SCR and OIT requirements have still cracked at welds under stress, underscoring that SCR is critical for mechanical durability. In essence, if a welded geomembrane is under tensile load, it's time to failure is governed by the resin's SCR (related to tie-molecule density) rather than OIT alone. A material with slightly lower OIT but very high SCR can outlast one with high OIT but poor SCR. Thus, SCR is paramount for weld ductility and long-term performance, as brittle cracking is fundamentally a slow-crack-growth phenomenon.

Polymer Structure: Molecular Weight, Crystallinity, and Tie-Chain Density

The microstructure of HDPE largely determines its stress-cracking resistance and therefore weld performance. HDPE is a semi-crystalline polymer made of crystalline lamellae (about ~50–60% by volume) tied together by amorphous chain segments. These connective molecules – known as "tie molecules" or tie chains – bridge adjacent crystal regions and impart toughness. The density and effectiveness of tie chains depend on resin characteristics: molecular weight distribution, comonomer content (branching), and resultant crystallinity. Key factors include:

- **Molecular Weight & Distribution:** Higher average molecular weight (Mw), higher Mz and a broad MWD (with a high-weight "tail") provide longer polymer chains that can span multiple crystals as tie molecules. Resins engineered with ultra-high MW fractions (e.g. bimodal HDPE resins used in "high-SCR" products) have dramatically improved slow-crack growth resistance. In contrast, lower-MW or narrow-distribution resins yield fewer effective tie chains, making welds more prone to brittle failure. Indeed, all HDPE geomembranes may perform similarly in a quick tensile test, but those with superior molecular architecture can have SCR values *100× greater* than others. This means a weld in a high-SCR

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resin can absorb long-term stress without cracking, whereas a low-SCR (lower MW) material may crack early under the same stress.

- **Crystallinity:** HDPE's crystallinity is a double-edged sword – high crystallinity gives chemical resistance and strength, but also means a stiffer, more brittle structure with fewer amorphous tie regions. Excessively crystalline material (large, perfect crystals with few interconnections) has low stress-crack resistance. More moderate crystallinity (achieved via short-chain branching from comonomers like butene/hexene) increases the amorphous content and promotes many small tie molecules linking crystals. Tie-chain density – the number and frequency of tie molecules per unit volume – rises as crystallinity is tempered. A higher tie-chain density distributes stress more evenly and slows crack propagation, yielding ductile behaviour. Conversely, if the weld or heat-affected zone becomes overly crystalline, it will lack sufficient tie chains and may crack in a brittle manner under load. In summary, resins with optimised molecular weight and branching (and thus high tie-chain density) produce welds with far greater ductility and long-term crack resistance.
- **Co-monomer Type/Content:** The short side branches introduced by co-monomers (e.g. ethylene-hexene or -octene copolymers) disrupt perfect crystal packing and help "tie the crystalline regions together". Resins with higher co-monomer content generally have slightly lower density and crystallinity but significantly improved flexibility and SCR. These resins can accommodate welding stresses better, as their welds retain more ductility. All else equal, an HDPE made with an octene co-monomer (yielding more tie molecules) will have a tougher, more crack-resistant weld than one with a minimal butene co-monomer content.

In practice, the weld microstructure itself is also crucial. The welding process melts and resolidifies polymer, which can alter local crystallinity. Ideally, a properly made weld cools fast enough to form a fine, small-spherulite microstructure similar to the parent sheet. If welding parameters cause slow

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cooling or overheating, the weld's crystalline morphology can change detrimentally (e.g. larger spherulites, higher crystallinity at the weld edge). Such changes reduce tie-chain density in the weld bead or heat-affected zone (HAZ), effectively lowering the SCR in the weld area relative to the parent sheet. This is why controlling weld conditions is vital – even a high-SCR base resin can develop a *low-SCR microstructure locally* if improperly welded, leading to brittle seam failures.

Why High OIT Doesn't Guarantee No Brittle Welds (Especially in the Field)

Oxidation Induction Time (OIT) is a measure of antioxidant reserves and oxidation resistance, but it is *not* a direct indicator of resistance to stress cracking. A high OIT value means the geomembrane is well-stabilised against thermal oxidation, but brittle weld failures can still occur due to mechanical and microstructural issues. Field incidents have shown that even geomembranes meeting high OIT specifications suffered crack failures at welds. The disconnect arises because brittle cracking (SCG – slow crack growth) can happen without any significant oxidation, if the stress and resin structure conditions allow it. As Koerner and Hsuan noted in their seminal study, stress cracking is a *"visually brittle failure that occurs at a constant stress lower than the yield stress"*, driven by polymer structure, not just oxidation. In essence, OIT protects against one cause of embrittlement (oxidative degradation), but it does not by itself confer toughness or crack-growth resistance.

Crucially, if an HDPE's antioxidants are intact (high OIT) but the material has poor SCR, a weld under constant stress can still nucleate a crack. Once a crack initiates (often at a flaw or stress concentrator), it can propagate through the crystalline network *even in the absence of oxidation*. A 2002 durability analysis by Peggs et al. highlighted that mechanical lifetime is a combined function of SCR and oxidative resistance. If a geomembrane remains under load, *"its ultimate failure time will then be a function of the basic SCR of the resin (the tie-molecule density)"* – meaning the inherent crack resistance of the polymer. They concluded that *"a material with a short OIT but high SCR could have a*

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longer time to failure than a material with a long OIT but a lower SCR". In other words, abundant antioxidants (long OIT) won't prevent a brittle failure if the polymer's structural toughness is insufficient.

Field conditions can exacerbate this. Real-world stresses and imperfections often trigger brittle weld failures despite high OIT:

- **Localised Strain and Stress Risers:** In the field, geomembranes experience thermal expansion/contraction, settlement, and hydraulic or wind uplift forces. These can concentrate strain along seams. Researchers using digital image correlation found that strains at HDPE seams can be 1.4–2× higher than in the adjacent sheet under tension. Such strain concentration at the weld (even if the material is not oxidised) can lead to craze formation and crack initiation in a susceptible resin. If the resin's SCR is low, the crack will grow slowly (SCG) until a brittle rupture occurs, even though OIT tests might still show adequate antioxidants remaining. Essentially, high OIT doesn't prevent mechanical stress from pulling tie molecules out of crystals over time.
- **Antioxidant Depletion in Weld Zones:** Welding itself exposes material to high temperatures, which can locally consume antioxidants. Studies have found that the heat-affected zone of welds can have a much faster depletion of Std-OIT compared to the parent sheet. Non-uniform heating can leave some spots in the weld nearly devoid of antioxidants (as low as 5% of virgin OIT in worst cases) while other spots retain much more. This means that a geomembrane sheet may test high in OIT, but the weld edges might already be at or near zero OIT after installation. In field conditions (especially elevated temperatures), those antioxidant-depleted HAZ regions can oxidize and embrittle faster, making them initiation points for cracks. Thus, high OIT values in the sheet can give a false sense of security – the critical weld zones may not share that same level of protection.
- **Cyclic Loads and Temperature Fluctuations:** Outdoor installations face day-night temperature swings and cyclic loading (e.g. water level

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changes, wind “fluttering” of exposed liners). These cyclic strains can drive crack growth in susceptible welds. A notable case involved an HDPE-lined pond that developed gas “whales” (buoyant bubbles). The whale expansion/contraction with ambient temperature put flexing stress on the welds; within 4 years, cracks formed parallel to the fusion welds in the HAZ. Lab analysis showed the cracked weld areas still had intact antioxidant (since only 4 years had passed), confirming oxidation was not the root cause. Instead, raised crystallinity in the weld HAZ (from an overly hot weld and slow cooling) made it brittle, and the cyclic flexing stress from the whale’s “breathing” caused a stress-crack to propagate along the weld edge. This case exemplifies that even with adequate OIT, field stresses can exploit any weakness in SCR or weld quality to produce a brittle failure.

In sum, OIT is necessary for long-term chemical stability, but not sufficient to ensure weld durability. Geomembrane industry data has even shown that many stress-cracking failures occurred in materials that *“met the GRI GM13 specification”* (including OIT limits) – the failures were instead attributed to factors like stress, cold weather, and welding issues. This challenges the industry norm of relying on OIT as a proxy for durability: a high OIT alone cannot guarantee against brittle welds if the material’s SCR is marginal or the weld is poorly executed.

Empirical Studies: SCR’s Effect on Weld Performance

A growing body of scientific studies, industry reports, and case investigations underscores the dominant effect of SCR on weld outcomes. Some key findings include:

- **Laboratory SCR Testing of Welds:** Peggs and Carlson (1990) performed early tests on HDPE seam samples to compare weld SCR to parent sheet SCR. Using the notched constant tensile load (NCTL) method (ASTM D5397), they found that cracks in seams often initiate in the heat-affected zone (HAZ) adjacent to the weld, where microstructural changes occur. Cracks typically started as small crazes at the weld edge

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in the lower sheet, then propagated perpendicularly under sustained load – a classic slow crack growth pattern. Their work hypothesised that a sudden change in crystallinity between the weld bead and the sheet can create a vulnerable plane for crack initiation. This was one of the first studies to directly link weld microstructure to stress-crack failures, emphasising that even a proper-looking weld can be the weak link if the resin SCR is low or the crystallinity gradient is high.

- **Unnotched vs. Notched Weld SCR:** Recent research suggests that traditional SCR tests on notched specimens may underpredict how a *well-made* weld will perform. Francey and Rowe (2022) examined fusion-welded HDPE seams and noted that unnotched weld samples tended to have SCR failure times closer to the intact sheet, whereas notched weld samples (with an artificial flaw) had much shorter times. Good-quality welds without significant flaws showed only a slight (3–15%) reduction in time-to-failure compared to the virgin sheet in stress-crack tests. This implies that if a weld is made under optimal conditions and the resin has high SCR, the weld can almost match the base material's crack resistance. However, welds with imperfections or overheating ("welding-induced geometric irregularities", WIGI) performed much worse – their SCR times were as low as a notched base sheet. In other words, a badly made weld in a high-SCR material could negate the resin's advantages, behaving like a pre-notched, crack-susceptible zone. These findings underscore how *both* material SCR and weld quality together determine seam longevity.
- **Accelerated Aging and SCR:** Long-term experiments have been conducted where welded seams are aged in harsh conditions (e.g. 85°C in leachate) to simulate many years of service. After 3+ years of such aging, tests show that fusion and extrusion welds still retained SCR comparable to unaged sheet, provided they were made correctly. No significant difference was seen between wedge welds and extrusion welds in terms of SCR over 40 months of immersion– countering a misconception that extrusion seams (which add new molten resin) might be weaker.

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However, the same study found that over-grinding or excessive "reworking" of weld areas markedly reduces SCR. Over-grinding (often done to smooth or repair extrusion seams) can thin the material or introduce micro-notches, which act as seeds for stress cracks. Thus, empirical data confirm that weld seams can be as durable as the sheet if made with high-SCR resin and careful technique, but any abuse to the weld zone will sharply drop its resistance to cracking.

- **Field Case Studies:** Numerous industry case studies have documented brittle failures and analysed their causes. The Australian pond case (Marta & Armstrong 2020) described earlier is one example where forensic analysis pinpointed raised weld crystallinity and weld-profile stress risers as the culprits, despite the material having acceptable OIT. Another example (cited by Peggs et al. 2014) showed stress cracking in exposed HDPE liner folds in a stormwater dam; the cracks initiated along the creased fold lines of a blown-film liner that saw daily thermal cycling. The common theme in these reports is that cracks almost always occur at points of stress concentration or anomaly – edges of welds, scratches, folded creases, etc. – and typically involve materials whose SCR was just at the lower end of specification. Investigators have noted that in many such failures, the geomembranes still met all standard specs (including OIT and tensile), highlighting that our standard tests (and minimum SCR requirements) can sometimes be inadequate for the real stresses encountered. These studies have fueled calls for more robust SCR criteria and better welding practices to ensure long-term performance.

In summary, empirical evidence strongly links higher SCR values with improved weld performance and longevity. They also show that poor welding can squander the benefits of a high-SCR resin. This has led to an industry consensus that stress crack resistance must be given equal importance to OIT and strength in specifications, especially for critical applications. As one report succinctly put it: stress-cracking is a durability issue that must be addressed through both material selection (high SCR resin) and quality installation.

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Welding Parameters That Exacerbate Brittle Behaviour

Even with a good HDPE resin, welding parameters (temperature, pressure, and speed/time) play a pivotal role in avoiding brittle seams. Certain welding conditions can induce brittleness – particularly in materials with marginal SCR – despite adequate antioxidant presence.

Key factors include:

- **Welding Temperature:** Excessive welding temperature or too slow a travel speed (heat input too high) can "overcook" the HDPE. Overheating during fusion welding was shown to cause localised over-crystallisation at the weld edges (HAZ), as the molten polymer slowly cools into larger, more perfect crystals. This raised crystallinity reduces ductility, essentially creating a brittle strip along the seam. A forensic analysis of cracked seams identified *"unacceptably high welding temperatures"* as a root cause, evidenced by an unusually high crystalline fraction in the failed HAZ. Overheating can also burn off antioxidants in the weld zone, accelerating local aging. On the other hand, too low a temperature or too fast a speed can yield a "cold weld" with incomplete fusion. Such under-welded seams often contain unbonded areas or weaknesses that act like notches. These cold weld defects concentrate stress and can initiate cracks under load. In short, staying within the optimal welding temperature window is critical – deviating high or low increases the risk of a brittle outcome, especially for lower-SCR materials that have a narrow margin for error.
- **Welding Pressure and Alignment:** In double-wedge fusion welding, the pressure (or nip force) must be balanced. Excessive pressure combined with high heat can extrude too much molten polymer out as "squeeze-out" (the bead that forms at seam edges). This leaves a thinner bonded section and also creates a sharp geometry at the weld toe. Such geometric irregularities act as stress concentrators – one study coined the term WIGI (welding-induced geometric irregularity) for these features, showing they correlate with significantly shorter SCR failure times. A high, acute-angle

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ridge or a deep imprint from the welding wedge can serve as the start point for a crack. Conversely, too little pressure can result in voids or incomplete contact, again creating stress risers. Proper alignment of welding equipment is also important; misalignment can lead to uneven heating or pressure and a non-uniform seam that might have brittle sections. Flat, consistent weld beads without sharp edges are the goal for maximising ductility.

- **Dwell Time (Speed):** The speed of a wedge welder (or travel speed for an extrusion bead) dictates how long the material stays molten and how it cools. A slower speed (longer dwell) at a given temperature means more heat input, potentially degrading the polymer or increasing melt pool size (leading to squeeze-out). It also lengthens cooling time under pressure, which can promote the growth of larger crystals (annealing effect). The case of *slower cooling leading to raised crystallinity* in a failed weld was documented, suggesting that rapid cooling is actually beneficial to keep the weld microstructure fine-grained. Thus, adhering to recommended speed for the conditions is vital. Manufacturers typically provide a "welding window" of temperature vs speed; staying in this window produces a weld that is strong *and* ductile. If site conditions change (e.g. ambient temperature drops or rises), adjustments are needed – otherwise an out-of-spec weld may result, with brittleness or poor strength. Field technicians know that improper calibration of wedge temperature, speed, or pressure is a common cause of faulty seams, so continuous monitoring and trial welds are standard practice.
- **Extrusion Weld Variables:** For extrusion fillet welding (used in repairs and detail work), operator skill is crucial. The parent sheet is usually ground or scraped to prepare the surface; over-grinding can reduce thickness and introduce micro-cracks, which later act as crack initiators. Also, using the wrong rod material (mismatch in melt index or density) can create a weld that has different crystallinity or stress response than the sheet, leading to a "weak link." Ensuring the extrudate rod is the same resin grade as the liner is recommended to maintain uniform properties.

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During extrusion, if the heat is too high or the travel too slow, the same issues of over-crystallisation and thermal degradation can occur. If the bead is laid too thin or unevenly, it may be brittle. Essentially, consistency and moderation in each parameter – enough heat to fuse but not burn, enough pressure to bond but not overstress, and a smooth, continuous application – are needed to avoid embrittling the weld.

It's worth noting that materials with lower intrinsic SCR are far less forgiving to welding parameter deviations. A resin with borderline SCR (just meeting the minimum) may fail in a brittle manner if the weld is even slightly overheated or has a minor notch, whereas a premium high-SCR resin might tolerate the same imperfection without cracking. For example, an overheated seam in a standard HDPE (500 hr SCR) might have a failure time "close to that of a notched sheet" (essentially, very short), but an overheated seam in an ultra-SCR resin could still yield several times longer time to failure. Nonetheless, best practice is to avoid creating any of these risky conditions. Industry reports on failures frequently cite *"excessive grinding and overheating of welds"* among the contributing factors to stress-crack failures. By strictly controlling weld temperature, pressure, and speed – and following qualified welding procedures – one can greatly minimise the chance of brittle welds, even for materials at the lower end of SCR.

Industry Recommendations and SCR Thresholds for Ductile Welds

Recognising the critical role of SCR in preventing brittle seams, industry experts and organisations have updated standards and issued guidance to improve weld outcomes:

- **GRI and ASTM Standards:** The Geosynthetic Research Institute (GRI) has progressively raised the bar on required SCR for HDPE geomembranes in its specification GM13. In the early 2000s the minimum stress crack resistance (via ASTM D5397, single-point NCTL) was 200 hours, later raised to 300 hours, and since 2014 it is 500 hours minimum. This change reflects the understanding that earlier thresholds were not sufficient to guarantee long-term durability. Today, ASTM

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D5397 (App. – the SP-NCTL test) at 50°C in a surfactant is the widely accepted measure of SCR, and 500 hr is considered the baseline for "ductile-brittle transition" performance. Leading manufacturers and specifiers now often demand "high stress-crack resistant" grades that far exceed 500 hr; some modern HDPE resins achieve >5,000 to >10,000 hr in this test. By comparison, the outdated ASTM D1693 bent strip test (once used for ESCR) is no longer trusted for geomembranes, as it can give misleadingly high hours that don't translate to actual stress-crack behaviour. The current guidance is clear: projects with any significant tensile strain on the liner *must* specify ASTM D5397 SCR testing and meet the 500+ hr criterion. Submitting only D1693 (bent strip) results is considered unacceptable.

- **Recommendations by Experts (Peggs, Koerner, Hsuan, Rowe, etc.):** Prominent figures in geosynthetics have urged the industry to go further in ensuring ductile welds:
  - Dr. Ian Peggs has repeatedly highlighted stress cracking issues and promoted the use of higher-SCR materials and better construction practices. At a 2014 conference, Peggs reported a *"resurgence"* of stress cracking in HDPE liners, despite the availability of better resins. Many failures he noted had occurred in geomembranes that technically *met* GM13, prompting a call for more stringent project-specific requirements. In a subsequent publication, Peggs recommended specifying HDPE with SCR > 1,000 hours (and >2,000 hours for critical applications). This essentially means using premium resins designed for exceptional slow-crack growth resistance (similar to PE100 pipe-grade polymers). Peggs also advocates for a High-Pressure OIT (HP-OIT) of >1,000 minutes for long-term oxidation resistance in critical projects (versus the 400 min minimum in GM13). Equally important, he emphasises installation controls: avoid excess slack (to minimise tensile stress), eliminate point loads under the liner, use compatible weld rod, and *"do not overheat the liner at welds"*. These recommendations

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collectively ensure that both the material and the welding process support ductile behaviour.

- **Dr. Robert Koerner and Dr. Grace Hsuan**, through research and publications (e.g. Koerner, Hsuan & Lord 1993), have long warned about stress cracking and its prevention. They were instrumental in developing improved test methods and advocating antioxidant and stress crack tests for lifetime predictions. One of their key messages was that stress cracking can be prevented by using stress-crack-resistant resins and by limiting the strain in service. Koerner's Geosynthetic Institute has suggested design measures like limiting allowable strain in HDPE liners (often to ~6% for exposed conditions) to reduce the stress that could induce cracking. Hsuan's work on lifetime prediction also shows that after antioxidants deplete, a high-SCR resin will hold up much longer before cracking than a low-SCR one – reinforcing the need for high SCR as a "safety net" after OIT is gone.
- **Dr. R. Kerry Rowe** has echoed the need for careful specification. Rowe commented that the standard GM13 should be viewed as a minimum baseline, suitable for low-risk applications, but that designers of critical facilities (e.g. hazardous waste landfills, mining tailings dams) should specify higher performance as needed . This might include requiring higher SCR, thicker liners, or special grades, to ensure the welds and liners can sustain the expected stresses. His collaborative research also underscores the importance of considering the weld HAZ in long-term performance – not just the sheet – because the HAZ can age faster and fail sooner if not accounted for.
- Manufacturers (e.g. Atarfil, Agru) and industry groups now often market "ESCR-enhanced" geomembranes, sometimes called "HSCR" (High Stress Crack Resistant) liners. These products achieve SCR values in the thousands of hours without sacrificing

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other properties. They have been developed in direct response to the lessons learned from field failures and research findings. The consensus among industry leaders is that investing in a high-SCR geomembrane, combined with strict welding QA/QC, is critical for ensuring ductile welds that won't crack in service.

In practical terms, many of these recommendations have been codified into guidance documents and project specs. For example, one landfill project might specify: *"HDPE geomembrane shall have stress crack resistance > 1,000 hr per ASTM D5397; resin shall be premium grade with proven high ESCR. Welds to be conducted by certified technicians within specified temperature/pressure ranges. No welding if ambient below X°C,"* etc. The goal is to eliminate brittle behaviour by addressing it on all fronts – material selection, engineering design, and installation control.

Conclusions and Industry Implications

The research and case evidence make it clear that preventing brittle welds in HDPE geomembranes requires looking beyond just high OIT values. Historically, the industry placed heavy emphasis on oxidation resistance (OIT) and short-term strength indices, assuming these would ensure longevity. However, findings in the last two decades have challenged these norms:

- **SCR vs. OIT:** We now know that Stress Crack Resistance is at least as important as OIT for long-term performance. A geomembrane that is well-stabilised (high OIT) but has borderline SCR can fail in a brittle manner under sustained stress, long before oxidation ever becomes an issue. This upends the once-common belief that "if the antioxidants last, the liner will last." Instead, both properties must be sufficient – and in many cases, enhancing SCR is the more direct way to prevent cracks. This has led to a shift in specifications (e.g. raising SCR requirements to 500 hr and beyond) and a realisation that a one-size-fits-all spec (like standard GM13) might be inadequate for demanding applications.
- **Microstructure Matters:** The role of polymer microstructure (molecular weight, tie chains, crystallinity) is now recognised in practice, not just

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theory. Resin choice can make or break a project's success. Many owners are willing to specify more robust, high-SCR resins for critical liners, even if they cost more, because the cost of failure is far higher. The industry has effectively acknowledged that not all "HDPE" is equal – two geomembranes can both be called HDPE and meet basic specs, yet one can have 10 times the stress-crack resistance of the other. This challenges the old norm of buying solely on price or generic specs. Quality of resin and proven performance history are being weighted more in procurement decisions.

- **Welding Quality and Training:** Another conclusion is that field practices need to keep pace with material advances. A high-SCR liner can still fail if mishandled. The highlighted cases of weld failures due to overheating or poor technique have driven home the point that installer training and QA/QC are vital. Industry bodies (e.g. IAGI – International Assoc. of Geosynthetic Installers) have certification programs for welders, and project engineers are more vigilant about monitoring welding parameters. The notion that "a weld is a weld" is dispelled – how the weld is made (and inspected) can determine whether the seam remains ductile or becomes an Achilles' heel. Specifications now often include detailed welding standard operating procedures and require trial seams and laboratory peel-and-shear tests to validate weld quality on-site.
- **Design for Less Stress:** Finally, there is a growing appreciation for designing geomembrane systems to minimise sustained stresses on the liner and seams. This includes using proper subgrade preparation (no sharp rocks or stress points), avoiding excessive slack or excessive tightness, controlling expansion (cover soils or ballast to limit temperature-induced strains), and accommodating differential settlement so the liner isn't pulled taut. If the liner can be kept in a low-strain state, the driving force for stress cracking is greatly reduced. This was sometimes overlooked in the past, but high-profile failures attributed to cyclic strain (e.g. at folds or welds) have made designers more cautious. Covering exposed liners to moderate temperature swings and UV

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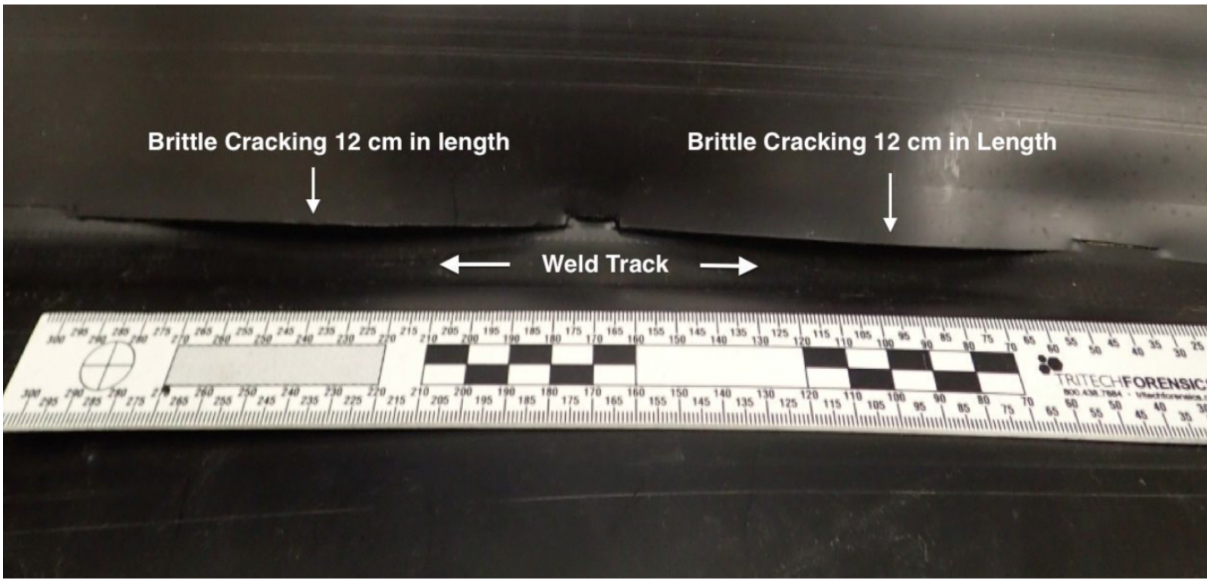
exposure is another recommendation to enhance longevity, even though HDPE is UV-stabilised – it also helps keep the liner in intimate contact with the subgrade, preventing "tenting" and flap stresses in wind.

In conclusion, brittle welds in HDPE geomembranes can occur despite high OIT when the resin's stress crack resistance or the welding execution is insufficient. Ensuring ductile, durable seams requires a holistic approach: specify a high-SCR resin (far above the minimum if the project is critical), maintain robust antioxidant levels, enforce proper welding parameters, and design/install the liner to minimise stress concentrations. Industry leaders like Peggs, Hsuan, Koerner, Rowe and others have sounded the alarm that simply meeting the bare minimums is not always enough. The notable lesson challenging old assumptions is that long-term durability is not guaranteed by chemistry (OIT) alone – the polymer's physical toughness (SCR) and the workmanship are equally determinative. By integrating these insights, the geosynthetics field is moving toward geomembrane systems with much greater reliability, where catastrophic brittle failures of seams become a thing of the past.



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