

This Sealant Assessment Table can be used to assess and compare different sealants when developing or selecting sealants for a well exposed to CO₂ during CO₂-injection and (geological) storage. Testing conditions, and the selection of relevant tests should be based on expected conditions and research needs for each application separately.

The Key abilities and Critical Properties included in this sheet are based on research performed as part of the ACT-CEMENTTEGRITY project (2021-2024). The included properties were selected based on existing regulatory documents as well as own research performed as part of the project. For more information regarding the selection of these properties, see the below reports and papers.

Note that the CEMENTTEGRITY project focused on the properties of the cured sealant materials, and did not take into account fluid state properties such as setting time or viscosity. As the fluid state properties are of great importance for sealant emplacement, for any new sealant material or specific application it should be ensured that these properties are also suitable.

References:

Van Noort, R. (2024) Overview of current standards and common other testing methods used in wellbore sealant assessment. CEMENTTEGRITY Deliverable 7.1, 2024-01-26.

Van Noort, R., M. Gupta, S. H. Hajiabadi, M. Khalifeh, A. Kvassnes, K. Li, A. Pluymakers, G. Starrs, B. Suryanto, G. Svenningsen, G. Ye (2024) Development and testing of novel cement designs for enhanced CCS well integrity. 17th Greenhouse Gas Control Technologies Conference 2024 (GHGT-17) proceedings, <https://ssrn.com/abstract=5010396>.

Van Noort, R. (2025) Critical properties and testing methods for sealants in CCS applications. CEMENTTEGRITY Deliverable 7.2, 2025-03-27.

NOGEP (2021) Industry Standard 45: Decommissioning of wells. NOGEP.

NORSOK (2021) D-010: Well integrity in drilling and well operations. NORSOK.

UK OG (2015) Guidelines on Qualification of Materials for the Abandonment of Wells (GQMAW). Oil & Gas UK.

UK OE (2022) Guidelines on Well Decommissioning for CO₂ Storage – Issue 1. Offshore Energies UK.

1) Ability to form and maintain a seal	Assessment methods	Methods notes	Results (description)	Impact of exposure (if done)	References
	Bond strength/shear tests	44 mm \varnothing sealant cylinder pushed out of 50 mm long mild steel casing (wall thickness 3.2 mm) - USA patent US11054353B2. Curing: 80°C, 30 MPa for 3 days; raised to 150 °C in 7 days, held 21 days. Conditioned at 80 °C before measurement.	Average peak shear stress (apparent bond strength) 3.54 MPa.	N.D.	
	Bulk conductivity/electrical tests	44 mm \varnothing sealant cylinder pushed out of 50 mm long mild steel casing (wall thickness 3.2 mm) - USA patent US11054353B2. Curing: 80°C, 30 MPa for 3 days; raised to 150 °C in 7 days, held 21 days. Conditioned at 80 °C before measurement.	Average bulk conductivity 0.0450 S/m. Average bulk conductivity 0.0384 S/m. Note that the electrodes were in the form of 2 stainless-steel rods, 2.4 mm diameter, 15 mm separation.	N.D.	
	Bond strength/shear tests	6 mm \varnothing stainless-steel tube (wall thickness 1 mm) pushed out of 70 mm long, 30 mm \varnothing sealant sheath	Average peak shear stress 1.8 MPa.	See below for thermal exposure.	
	Annular leakage/hydraulic sealability	N2-flow rate measured along annular contact by applying 0.3 Mpa pressure to one end of cylinder; other end open to atmosphere.	Leakage rates of ~0.2 ml/min. Note that these measurements were performed on an annular contact of sealant around stainless steel with a contact diameter of 6 mm.	See below for thermal exposure.	
2) Ability to resist CO2-containing fluids	Exposure method	Conditions and fluid used	Results (description)	Impact of compound exposure (if done)	References
	Batch	12 mm \varnothing , 30 mm long cylinder; wet supercritical CO2, 80 °C, 10 MPa.	Full carbonation of free Ca(OH)2 within 4 weeks. At 16 weeks, further chemical and microstructural alteration in outer 1320 μ m, with degradation in outer 300 μ m.	N.D.	
	Batch	12 mm \varnothing , 30 mm long cylinder; CO2-saturated water, 80 °C, 10 MPa.	Full carbonation of free Ca(OH)2 within 4 weeks. At 16 weeks, further chemical and microstructural alteration in outer 1400 μ m, with degradation in outer 400 μ m.	N.D.	
	Batch	12 mm \varnothing , 30 mm long cylinder; wet supercritical CO2 with 1.6 mol% H2S, 80 °C, 10 MPa.	Full carbonation of free Ca(OH)2 within 4 weeks. At 16 weeks, further chemical and microstructural alteration in outer 700 μ m, with no significant degradation. S enrichment throughout the samples.	N.D.	
	Batch	12 mm \varnothing , 30 mm long cylinder; CO2-saturated water, 1.6 mol% H2S in CO2-phase, 80 °C, 10 MPa.	Full carbonation of free Ca(OH)2 within 4 weeks. At 16 weeks, further chemical and microstructural alteration in outer 1200 μ m, with degradation in outer 50 μ m. S enrichment throughout the samples.	N.D.	
	Batch	12 mm \varnothing , 30 mm long cylinder; supercritical CO2 equilibrated with concentrated H2SO4, 80 °C, 10 MPa.	Full carbonation of free Ca(OH)2 within 4 weeks. At 16 weeks, further chemical and microstructural alteration in outer 2700 μ m, with some degradation in outer 300 μ m. S contents somewhat enriched throughout the samples.	N.D.	
	Flow-through	38 mm \varnothing , 80 mm long cylinder; wet supercritical CO2, 80 °C, 13.8 MPa Pconf, 11.7 MPa Pup; 8.3 MPa Pdown.	Mostly relatively constant flow over full duration. Increased hardness in carbonated matrix; depth to unaffected >80 mm at 180 days.	N.D.	
	Flow-through	38 mm \varnothing , 80 mm long cylinder; CO2-saturated water, 80 °C, 13.8 MPa Pconf, 6.2 MPa Pup; 1.4 MPa Pdown.	Initial rapid flow with strong decrease in first days. Then, constant flow-rate over full duration. Increased hardness in carbonated matrix; depth to unaffected 20 mm at 90 days; 30 mm at 180 days. Some mechanical degradation at injection surface; to 5 mm depth at 180 days.	N.D.	
3) Ability to withstand thermal shocks and cycles	Exposure method	Exposure conditions	Results (description)	Impact of compound exposure (if done)	References
	Unconfined, solid sealant cylinder	Sample length 70 mm, \varnothing 30 mm. 120 °C sample shocked in 20 °C water bath, 8 cycles	CT-scanning shows no changes due to thermal shock. UCS increased by ~47 %.	N.D.	
	Unconfined, solid sealant cylinder with channel drilled along axis	Sample length 70 mm, \varnothing 30 mm, drilled hole diameter 4 mm. 120 °C sample flushed with 20 °C water, 8 cycles	CT-scanning shows no changes due to thermal shock. No significant change in UCS.	N.D.	
	Confined, solid sealant cylinder with channel drilled along axis	Sample length 70 mm, \varnothing 30 mm, drilled hole diameter 4 mm. 120 °C sample confined at 1.5 or 10 MPa, flushed with 20 °C water, 8 cycles	No crack formation seen in CT-scans. ~2.6 % (at 1.5 MPa) to 7.3 % (at 10 MPa) increases in UCS after confinement and thermal shocking, due to confinement.	N.D.	
	Unconfined, sealant cylinder cast around stainless-steel tube	Sample length 70 mm, \varnothing 30 mm, tube diameter 6 mm. 60 °C sample flushed with 5 °C water through tube, 16 cycles	No crack formation seen in CT-scans. Leakage rates increase by ~1.2x. Shear stress needed to separate tube from annular seal decreased by ~7.3 %.	N.D.	
	Confined, sealant cylinder cast around stainless-steel tube	Sample length 70 mm, \varnothing 30 mm, tube diameter 6 mm. 60 °C sample confined at 1.5 MPa, flushed with 5 °C water through tube, 8 cycles	No crack formation seen in CT-scans. Minor decrease in leakage rate likely due to confinement. Shear stress needed to separate tube from annular seal increased by ~10 %.	N.D.	

Sealant for CCS - critical properties assessment

Property	Relevance (Req; KII; FSM; CO2; TSC)	Reference sample	CO2-exposed	Exposed to thermal shocks/cycling
Permeability	Req; KII; CO2			
Water, constant flow		0.18-0.19 x 10-18 m2 (after curing) 0.22 x 10-18 m2 (180 days reference)	0.16 x 10-18 m2 (180 days CO2-sat H2O); 0.30 x 10-18 m2 (180 days sc. CO2)	N.D.
Mechanical properties				
Compressive strength	Req; KII; FMS; TSC	34-35 MPa	28 MPa (90 days CO2-sat H2O) to 22 MPa (180 days CO2-sat H2O)	33 MPa for unexposed reference sample. 46-51 MPa (after 8 unconfined quenches) to 32 MPa (after 8 unconfined flushes). 34-36 MPa (after 8 confined flushes at 1.5-10 MPa confining pressure).
Tensile strength	Req; KII; FMS; TSC	3.8-4.7 MPa	2.3 MPa (90 days CO2-sat H2O) to 2.5 MPa (180 days CO2-sat H2O)	N.D.
E-modulus	Req; KII; TSC	9.2-9.9 GPa	10.0 GPa (90 days CO2-sat H2O) to 10.4 GPa (180 days CO2-sat H2O)	N.D.
Poisson ratio	Req; KII; FMS; TSC	0.24-0.26	0.26 (90 days CO2-sat H2O) to 0.25 (180 days CO2-sat H2O)	N.D.
E/C-ratio	Req; KII; TSC	271-284	359 (90 days CO2-sat H2O) to 477 (180 days CO2-sat H2O)	N.D.
Volumetric behaviour				
During curing	Req; FMS	N.D.	-	-
Over time	Req; FMS	N.D.	N.D.	N.D.
Thermal properties				
Thermal diffusivity	TSC	0.80 (mm2/s)	N.D.	N.D.
Expansion coefficient	TSC	9.40 (10-6/K)	N.D.	N.D.
Mass/density	KII; CO2	1.910-1.95 g/ml (water-saturated, measured on ~1.2 cm diameter, 3 cm long cylinders) 1.46 g/ml (dried)	Exposed to wet sc. CO2, 4 weeks: 2.03 g/ml; 8-16 weeks: 2.01 g/ml. Exposed to CO2-saturated water 4-8 weeks: 2.02-2.03 g/ml; 16 weeks: 1.98 g/ml. Exposed to wet sc. CO2 with H2S, 4 weeks: 2.05 g/ml; 16 weeks: 2.00 g/ml. Exposed to CO2-saturated water with H2S, 4 weeks: 2.01 g/ml; 16 weeks: 2.03 g/ml. Exposed to sc. CO2 with H2SO4, 4-8-16 weeks: gradual decrease from 1.79 to 1.74 g/ml.	N.D.
Composition	Req; CO2			
Chemical, Mineralogical, Microstructure		Loose aggregate of olivine, quartz and unreacted clinker grains held in a soft, low-density matrix with heavier, harder, accicular "CSH-islands".	Batch exposure to wet supercritical CO2 caused recrystallization of the matrix to form round carbonate "islands". Very low-density matrix, i.e., degradation, in the outer ~300 µm, with much more dense precipitate structure inwards from that. Reduced Ca/Si-ratios, mostly in the outer ~300 µm. Extrapolation of carbonation depths not possible. Exposure to CO2-saturated water caused leaching (removal of Ca), with alterations at the exposure surface up to ~1.4 mm after 16 weeks (batch). Some degradation in the outer ~400 µm (16 weeks batch). Alt. 5mm degradation depth after 180 days flow-through. Extrapolated carbonation depth after 1000 years 1.3 m.	CT-scanning (32 µm/voxel resolution) showed no change in microstructure after 8 unconfined quenches, 8 unconfined flushes, or after confined flushing.

Req: Required property (Norsok D010, GQMAW, and/or Nogepe45)
 KII: Key integrity indicator (Norsok D010, and/or GQMAW)
 FMS: Ability to Form and Maintain a Seal
 CO2: Ability to resist exposure to CO2-containing fluids
 TSC: Ability to withstand Thermal Shocks or Cycling