

This Sealant Assessment Table can be used to assess and compare different sealants when developing or selecting sealants for a well exposed to CO<sub>2</sub> during CO<sub>2</sub>-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 CO<sub>2</sub> 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) 1.51 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 0.0357 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 2.4 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 0.4-0.5 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 1020 $\mu$ m, with degradation in outer 120 $\mu$ 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 1800 $\mu$ m, with degradation in outer 100 $\mu$ 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 $\mu$ m, with degradation in outer 50 $\mu$ m. 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 2200 $\mu$ m, with degradation in outer 100 $\mu$ 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 1280 $\mu$ m, with some degradation in outer 150 $\mu$ m. S content 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 17 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 8 mm at 90 days; 11 mm at 180 days. Some mechanical degradation at injection surface; to 0.5 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 crack formation due to thermal shock. UCS reduced by ~50 %	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 crack formation due to thermal shock. UCS reduced by ~27 %	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. ~5.8 % (at 1.5 MPa) to 6.8 % (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 ~1.7x. Shear stress needed to separate tube from annular seal decreased by ~16 %.	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 ~43 %.	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		0.05-0.06 x 10-18 m2 (after curing) 0.04 x 10-18 m2 (180 days reference)	0.024 x 10-18 m2 (180 days CO2-sat H2O); 0.031 x 10-18 m2 (180 days sc. CO2)	N.D.
<b>Mechanical properties</b>				
Compressive strength	Req; KII; FMS; TSC	76-80 MPa	86 MPa (90 days CO2-sat H2O). No Value (180 days CO2-sat H2O)	80 MPa for unexposed reference sample. 34-46 MPa (after 8 unconfined quenches) to 58 MPa (after 8 unconfined flushes). 85-86 MPa (after 8 confined flushes at 1.5-10 MPa confining pressure).
Tensile strength	Req; KII; FMS; TSC	6.5-7.6 MPa	6.3 MPa (90 days CO2-sat H2O) to 6.0 MPa (180 days CO2-sat H2O)	N.D.
E-modulus	Req; KII; TSC	14.6-16.3 GPa	15.8 GPa (90 days CO2-sat H2O) to 15.3 GPa (180 days CO2-sat H2O)	N.D.
Poisson ratio	Req; KII; FMS; TSC	0.26-0.27	0.23 (90 days CO2-sat H2O) to 0.25 (180 days CO2-sat H2O)	N.D.
E/C-ratio	Req; KII; TSC	188-193	183 (90 days CO2-sat H2O). No value for 180 days CO2-sat H2O.	N.D.
<b>Volumetric behaviour</b>				
During curing	Req; FMS	N.D.	-	-
Over time	Req; FMS	N.D.	N.D.	N.D.
<b>Thermal properties</b>				
Thermal diffusivity	TSC	0.523 (mm2/s)	N.D.	N.D.
Expansion coefficient	TSC	10.93 (10-6/K)	N.D.	N.D.
<b>Mass/density</b>				
	KII; CO2	1.90-1.94 g/ml (water-saturated, measured on ~1.2 cm diameter, 3 cm long cylinders) 1.49 g/ml (dried)	Exposed to wet sc. CO2, 4-8 weeks: 2.07 g/ml; 16 weeks: 2.04 g/ml. Exposed to CO2-saturated water 4-8-16 weeks: gradual decrease from 2.06 to 2.00 g/ml. Exposed to wet sc. CO2 with H2S, 4 weeks: 2.08 g/ml; 16 weeks: 2.02 g/ml. Exposed to CO2-saturated water with H2S, 4 weeks: 2.07 g/ml; 16 weeks: 2.04 g/ml. Exposed to sc. CO2 with H2SO4, 4-8-16 weeks: gradual decrease from 1.93 to 1.86 g/ml.	N.D.
<b>Composition</b>				
Chemical, Mineralogical, Microstructure	Req; CO2	Homogeneous, dense CSH gel surrounding remaining grains of quartz and unreacted clinker, as well as local areas of Mg-hydroxide.	Batch exposure to wet supercritical CO2 caused minor degradation in the outer ~100 µm, with densification due to carbonate precipitation inwards of that. No significant impact on Ca/Si-ratios. Little to no leaching or other chemical change. Extrapolated carbonation depth after 1000 years 0.8 m.  Exposure to CO2-saturated water caused some leaching (removal of Ca), with minor degradation at the exposure surface, up to ~1.8mm after 16 weeks (batch). Strong degradation in outer ~100 µm (16 weeks batch). Alt. ~0.5mm degradation depth after 180 days flow-through. Extrapolated carbonation depth after 1000 years 0.5 m.	CT-scanning (32 µm/voxel resolution) showed increase in voids from 0% to 1.0% (after 8 unconfined quenches) or 0.27% (after 8 unconfined flushes). No change observed 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