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TECHNICAL SUMMARY

STRATIFLEX™ BY EYECULAR

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EYECULAR
Innovating Thermal Stratification

1 Bill of Material

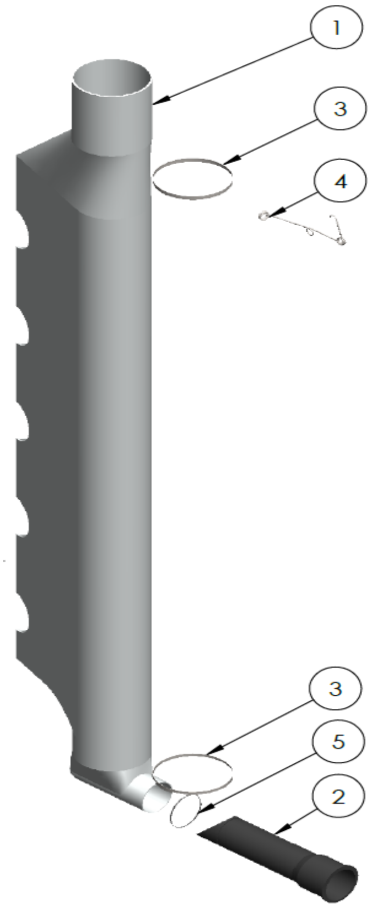

Figure 1: StratiFlex™ with single components

**The Bill of Material includes two Tefzel ETFE cable ties (not visible in the picture). One is applied in order to lock the Topspring to the Spacer, and the other one to close and lock the Expander*

Item No.	Description	Material	Drinking Water Approval	Durability
1	Film	ETFE (ET 6235 Z)	DVGW W270; WRAS	No oxidation/ degradation/ bacterial growth
2	Feedpipe	PP-R (BC245MO)	WRAS	Good creep- and stress resistance
3	Expander	Duplex (EN 1.4462)	DWI – Recognized Steel Grade	Excellent stress-, crevice-, and pitting corrosion resistance
4	Topspring			
5	Lockring			
6	Cabletie (not displayable)	ETFE (Tefzel®)	Approved for Potable Drinking Water Applications	No oxidation/ degradation/ bacterial growth

Figure 2: StratiFlex™ Component Properties

2 Material Durability and Thermal Stability

2.1 ETFE

ETFE (Ethylene-tetrafluoroethylene copolymer) is a fluoropolymer with superior properties, such as mechanical strength, thermal stability and non-stick properties. Due to its significant durability and environmental stability, it is often used in agricultural and architectural constructions, moreover it is also seen in some high-end drinking water components.

Mechanical and thermal properties of the ETFE Film grade used for StratiFlex™, defined by the producer Nowofol, are summarized in the table below.

Nowoflon ® ET 6235 Z – Physical Properties	
Tensile Strength	50 MPa
Tensile strain at break	500 %
Tensile Stress at 10% strain	23 MPa
Tensile Modulus (0.05-1%)	1000 MPa
Thermal Service Range	-200 to 150 °C
Melting Point	265°C

Figure 3: Nowoflon Physical Properties. Nowofol (2017): ET 6235 Z Product Data Sheet

Test of ageing

Samples of ETFE film with 50µm thickness have been aged and tested by the Danish Technological Institute (DTI)[1], in order to evaluate if 20 years of operation in a hot water tank, would be a likely life time for the ETFE film. The ageing tests were performed separately in air and de-mineralized water at both 95°C and 150°C, resulting in a total of four ageing tests.

Conditions for the ageing tests:

- Temperature: 95°C and 150°C (separately)
- Chemical environment: Air and DI-W (separately)
- Time: 52 weeks
- Resistance to creep: Extension at 2 MPa, tensile load
- Sampling sequence
  - Film: control test, 1, 12, 26, 52 week(s)
  - Welded film: control test, 1, 12, 26, 52 week(s)
- Number of samples: 5 and 3 repeated measurements at each sampling time for tensile and creep respectively

The procedure of the tests follow the below-mentioned standards:

- DN/EN ISO 527-3 (1996), Plastics – Determination of tensile properties – Part 3: Test conditions for films and sheets.
- DS/EN ISO 527-1:2012, Plastics – Determination of tensile properties – Part 1: General principles.

[1] https://www.dti.dk/testing

- DS/EN ISO 11501 (2004), Plastics film and sheeting – Determination of dimensional changes on heating.
- ISO 4593-(1993), Plastics – Film and sheeting – Determination of thickness by mechanical scanning

The following 4 most important durability properties were defined and tested by DTI:

1. Surface chemical modification (oxidation)
2. Dimensional stability
3. Tensile properties (including welding strength)
4. Creep

The test parameters and results are summarized in the table below.

		Control Value	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Temperature		-	95°C	150°C	95°C	150°C
Time		-	52 Weeks	52 Weeks	52 Weeks	52 Weeks
Air/Water		-	Water	Water	Air	Air
Mech. Properties Tensile Strength	None Welded	54 MPa	54 MPa	50 MPa	53 MPa	36 MPa
	Welded	42 MPa	40 MPa	40 MPa	44 MPa	30 MPa
Mech. Properties Elongation at break	None Welded	433%	311%	303%	320%	198%
	Welded	428%	439%	500%	493%	20%
Creep Resistance None Welded		-	< 3% change in elongation	< 8% change in elongation	< 3% change in elongation	<6% change in elongation
Dimensional Stab. (swelling/weight) None Welded		-	No significant changes	No significant changes	No significant changes	No significant changes
Surface Modification (oxidation) None Welded		-	No sign of oxidation/ degradation/ Modification	No sign of oxidation/ degradation/ modification	No sign of oxidation/ degradation/ modification	No sign of oxidation/ degradation/ modification

Figure 4: ETFE Test Scenarios. Based on: DTI (2017): ETFE Test Report

Even under elevated thermal conditions, the ETFE only shows insignificant or no changes of chemical composition, mechanical and thermal properties, confirming the long-term durability of the ETFE film. The 4 important properties will be analyzed in the following.

Surface chemical modification (oxidation)

In order to evaluate oxidation, degradation or other modifications of the chemical composition of the ETFE surface, FTIR spectroscopy was performed in wavenumber range of 400-4000 cm^{-1}. The tests were done with a Nicolet iS50 FT-IR Spectrometer. By infrared spectroscopy it is possible to assess the chemical composition of the ETFE. This will allow evaluation of any changes in the surface chemistry.

In all four test scenarios, no change in chemical composition of the surface was detected, implying no signs of oxidation, degradation or other chemical compositional changes. This also states that ETFE does not leach anything to the water, making it suitable for drinking water applications.

Dimensional stability

The swelling in thickness, length (machine direction and transverse direction) and weight of ETFE was observed over 52 weeks with the temperatures and conditions defined above. The tests were performed to evaluate if the ETFE film is dimensionally stable at elevated temperature over long time periods. Dimensional stability is important, as a change in dimensional stability would mean that water has been absorbed. Absorption of water could decrease the mechanical properties, and can in worst case scenarios cause failure.

In all four test scenarios, no significant changes in terms of swelling were observed. This indicates that even at long term exposure at elevated temperatures, the ETFE film is stable.

Tensile testing

Tensile properties were tested on samples aged according to the description above. Tensile properties of both, non-welded and welded films were tested, to evaluate the change in tensile strength. Welding strength is tested, as the ETFE foil is welded as a part of the manufacturing of StratiFlex™.

Testing was performed with a Shimadzu Tensile testing machine with associated auxiliary equipment (100N load cell). Tests were performed in a controlled environment at 23±2°C and 50±5% RH. Test speed was 100mm/min with a gauge length of 22mm.

At both 95°C and 150°C in DI-W no significant change in tensile strength over a period of 52 weeks was found for either the welded or the non-welded samples. In hot-air at both temperatures, however, a minor change in tensile strength was observed. Small changes in elongation at break were observed for all samples, except for the welded films in both air and DI-W at 95°C. Furthermore, one major change in elongation was found in hot-air at 150°C.

Overall, changes in the mechanical properties at elevated temperatures over 52 weeks should be expected, regardless of the polymer. Time, temperature and stress are all known factors for weakening polymers over time. Nevertheless, the ETFE film did perform very well especially in water, considering the drastically elevated temperatures. The results are deemed to be in accordance of what was expected, again stating that ETFE is a very strong and durable polymer.

Creep

ETFE's resistance to creep was evaluated over 52 weeks at different temperatures and environments, according to specifications above. All samples were loaded at a stress of 2 MPa, relative to their cross section. Relative change in length was measured at the sample rate specified above, and finally creep resistance was assessed.

Creep resistance is an important aspect, as the ETFE film will be mounted under constant stress during its entire lifetime.

Based on the obtained creep measurements during testing and experimental work performed by Yintang and Minger (2015), creep predications were calculated. Reference temperature was 95°C and calculated with a confidence interval at 95%. Testing and calculations are done resembling real case loading scenarios. The load on ETFE during operation is 100g, which will induce a different stress, depending on the size (cross-section area) on the StratiFlex™. In the table below, a summation of creep predications of the different sizes of StratiFlex™ at 60°C for 10 and 30 years, can be found.

Predicted creep confidence								
Extrapolated creep % at 60°C during service life of 10 and 30 years in DI-W								
StratiFlex™	Ø92 mm		Ø102 mm		Ø130 mm		Ø150 mm	
Years	**10**	**30**	**10**	**30**	**10**	**30**	**10**	**30**
-2,5%	0.05%	0.06%	0.04%	0.06%	0.03%	0.05%	0.03%	0.04%
Average	**0.10%**	**0.13%**	**0.08%**	**0.11%**	**0.07%**	**0.09%**	**0.06%**	**0.08%**
+2,5	0.19%	0.26%	0.17%	0.22%	0.14%	0.18%	0.12%	0.16%
Avg. increase in length in mm per meter	0.1mm	**0.13mm**	0.08mm	0.11mm	0.07mm	0.09mm	0.06mm	0.08mm

Figure 5: Predicted creep confidence. Calculations based on DTI (2017) and Yintang, L., Minger, W. (2015)

The largest increase in length due to creep is 0.13mm per meter, and has been found for the Stratiflex™ size of 92mm with an operation time of 30 years. As the top-spring is designed to be able to allow up to 5mm of creep, we can conclude that StratiFlex™' performance will not be compromised by creep during 30 years of operation.

2.2 PP-R

PP-R (polypropylene) BC245MO is a stiff high impact polypropylene copolymer, characterized by good stiffness, good creep resistance, excellent stress cracking resistance and very high impact strength. PP-R is suitable for use in hot water up to 85°C.[2] Note that the PP-R is used for the feedback, which is always located in the bottom (colder) part of the tank.

Heat Deflection Temperature	85°C
Melting Temperature	230-260°C
Tensile Stress at Yield (50mm/min)	25 MPa

Figure 6: BC245MO - Physical Properties. Borealis (2013): Polypropylene Data Sheet

2.3 Duplex Steel

For DHW tanks, StratiFlex™' metal components consist exclusively of Duplex Steel, one of the most corrosion-proof steel grades available. Independent of the component, wire and strip-steel, the same steel grade is used:

- The grade used for the two strip steel components; "Spacer" and "Expander" is "SpringFlex" (En 1.4462) [3] manufactured by the company Sandvik
- The same grade by Sandvik is used for the two wire steel components; "Topspring" and "Lockring" possessing the same corrosion properties.[4]

In the following summary, both Duplex steel components are referred to as "Duplex steel".

The Duplex steel shows excellent resistance especially against; stress corrosion cracking in chloride containing environments, pitting- and crevice corrosion. The steel grade does furthermore show a high tensile strength with high modulus of elasticity.

[2] BC245MO - Physical Properties. Borealis (2013): Polypropylene Data Sheet
[3] Sandvik (2016). Springflex Strip Steel Datasheet.
[4] Sandvik (2015). Springflex ESP (Wire)

Pitting Corrosion resistance

With a higher share of chromium and molybdenum than conventional stainless steel, Duplex steel possesses a Pitting Resistance Equivalent (PRE) of >35. This makes it especially resistant in chloride containing environments and is even corrosion proof in seawater.

Crevice corrosion resistance

For conventional stainless steel grades corrosion in crevices and cracks occur e.g. in contact points between metals or under deposits on the metal. Duplex steel offers, however, a considerable better prevention of crevice corrosion then conventional stainless steels.

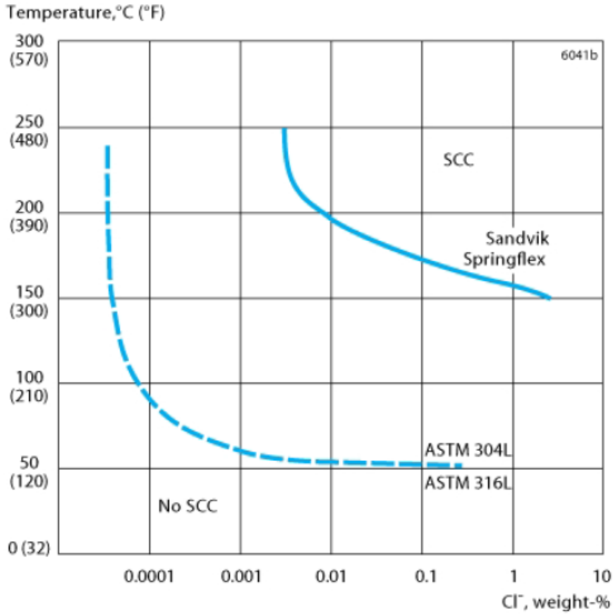

Figure 7: Resistance to stress corrosion cracking. Sandvik (2016). SpringFlex Strip Steel Datasheet.

Stress corrosion cracking resistance

The diagram to the right illustrates the reaction of the Duplex steel and conventional stainless steel under different temperature conditions and chloride concentrations. Compared to conventional stainless steel grades, Duplex steel is characterized by a superior resistance to stress corrosion cracking.

With service temperatures from -100°C to 300°C, Duplex steel is therefore suitable for high temperature variations in hot water storage tanks.

3 Function Durability[5]

Two accelerated durability tests have been conducted by the Department of Civil Engineering at the Technical University of Denmark (DTU)[6]. The tests were simulating the long-term operation of StratiFlex™ in both DHW and technical water.

3.1 DHW

The DHW durability test was performed in a 400-liter domestic hot water tank, focusing on the impact of lime scaling on StratiFlex™. Due to the high hardness of water at the test facility of 21° dH, the test equipment had to be repaired and several parts replaced twice during the test phase. StratiFlex™, however, remained unaffected by lime scaling. The test ran for 24 months with more than 5700 charge cycles, demonstrating the satisfactory resilience of StratiFlex™.

The calculated and extrapolated lifetime varies significantly, depending on the water hardness and the yearly hot water consumption of the household. Based on the test results, a life time of

[5] Dragsted, J., Furbo, S. (2017): Durability tests of inlet stratifiers from EyeCular Technologies Aps. DTU Department of Civil Engineering

[6] http://www.bfi.byg.dtu.dk/english

more than **20-70 years** for a yearly one family house with a hot water consumption of 5.800 kWh and 1.700 kWh respectively, was estimated.

3.2 Technical water

More than 5100 charge cycles with technical water have been carried out in a 400-liter buffer tank, focusing on corrosion and deposits adhering on StratiFlex™. When the test was ended after two years of testing, the StratiFlex™ performance was unaffected. This result indicated a lifetime of at least **5.5 and 18 years** for 20 m^2 and 6 m^2 solar heating systems respectively. The lifetime is, however, considering the abovementioned test circumstances assumed to be significantly longer.

4 Drinking Water Approvals

4.1 ETFE-film[7]

According to standards set by the German Technical and Scientific Association for Gas and Water, the fluoroplastic component ET6235Z has been tested in compliance with the DVGW W270 screening test. The test examines the grow of microorganisms (i.e. bacteria) on the surface of the component. For the applied polymer defined above, no growth of microorganisms has been detected. The polymer therefore fulfills prerequisites set by DVGW W 270 for the use in drinking water applications.

The compliance with the DVGW W 270 standards thereby also complies with one of the preconditions for KTW-approval.

ET6235Z is moreover listed as one of the WRAS (Water Regulations Advisory Scheme), British water regulation authority, drinking water approved materials[8].

4.2 Tefzel ETFE

The DuPont Tefzel ETFE resin meets the requirements for drinking water approval according to DuPont.[9]

4.3 PP-R

The grade BC245MO by Borealis AG is a drinking water approved material in compliance with WRAS (Approval Number 1407525)[10].

4.4 Duplex Steel

The applied Duplex steel grade En 1.4462 is a DWI drinking water approved stainless steel grade.[11]According to the German Environmental Agency "Umweltbundesamt" and WRAS, all stainless-steel grades are suitable for the direct use with drinking water, as long as they are not heavily corroded.[12]

[7] Dyneon (2017): 3M Dyneon Fluoroplastic ET 6235Z. Europäische Standards für den Trinkwasserkontakt.
[8] WRAS (2017): Approval Number: 1307515
[9] DuPont (2011): DuPont Fluoropolymers – Tefzel ETFE
[10] WRAS (2017): Approval Number 1407525
[11] DWI (2017): List of Drinking Water Approved Products
[12] Umweltbundesamt (2017): http://www.umweltbundesamt.de/sites/default/files/medien/374/dokumente/2_aenderung_bewertungsgrundlage_fuer_metallene_werkstoffe_im_kontakt_mit_trinkwasser_komplett_fuer_internet.pdf

5 Conclusion

StratiFlex™ consists of just three different materials: ETFE, PP-R and Duplex Steel. All materials and grades have been carefully selected, to outlast the life time expectancy of 20 years of commercially available hot water tanks. The testing concludes, that the materials used in StratiFlex™, have no issues in the hot water environments even at long time periods.

StratiFlex™' efficiency has been tested with regards to long term operation in both DHW and technical water. It has been demonstrated that the lifetime expectancy of StratiFlex™ more than exceeds 20 years of operations.

Finally, all materials have been selected to comply with material regulations for the use of StratiFlex™ in DHW tanks.

6 Appendices

All appendices can be downloaded from EyeCular's Customer Webcenter[13]".

1. DTI (2017): Test report ETFE
2. DWI (2017): List of Drinking Water Approved Products
3. Dragsted, J., Furbo, S. (2017): Durability tests of inlet stratifiers from EyeCular Technologies Aps. DTU Department of Civil Engineering
4. Dyneon (2017): 3M Dyneon Fluoroplastic ET 6235Z. Europäische Standards für den Trinkwasserkontakt. Novofol certificate
5. Sandvik (2016): Springflex Strip Steel datasheet.
6. Sandvik (2015). Springflex ESP (Wire) datasheet
7. DuPont (2011): Tefzel – Fluoropolymer Properties Handbook
8. WRAS (2017): Approval Number 1407525
9. Yintang, L., Minger, W. (2015): Uniaxial creep property and viscoelastic-plastic modelling of ethylene tetrafluoroethylene (ETFE) foil.

[13] http://eyecular.com/customerwebcenter/