

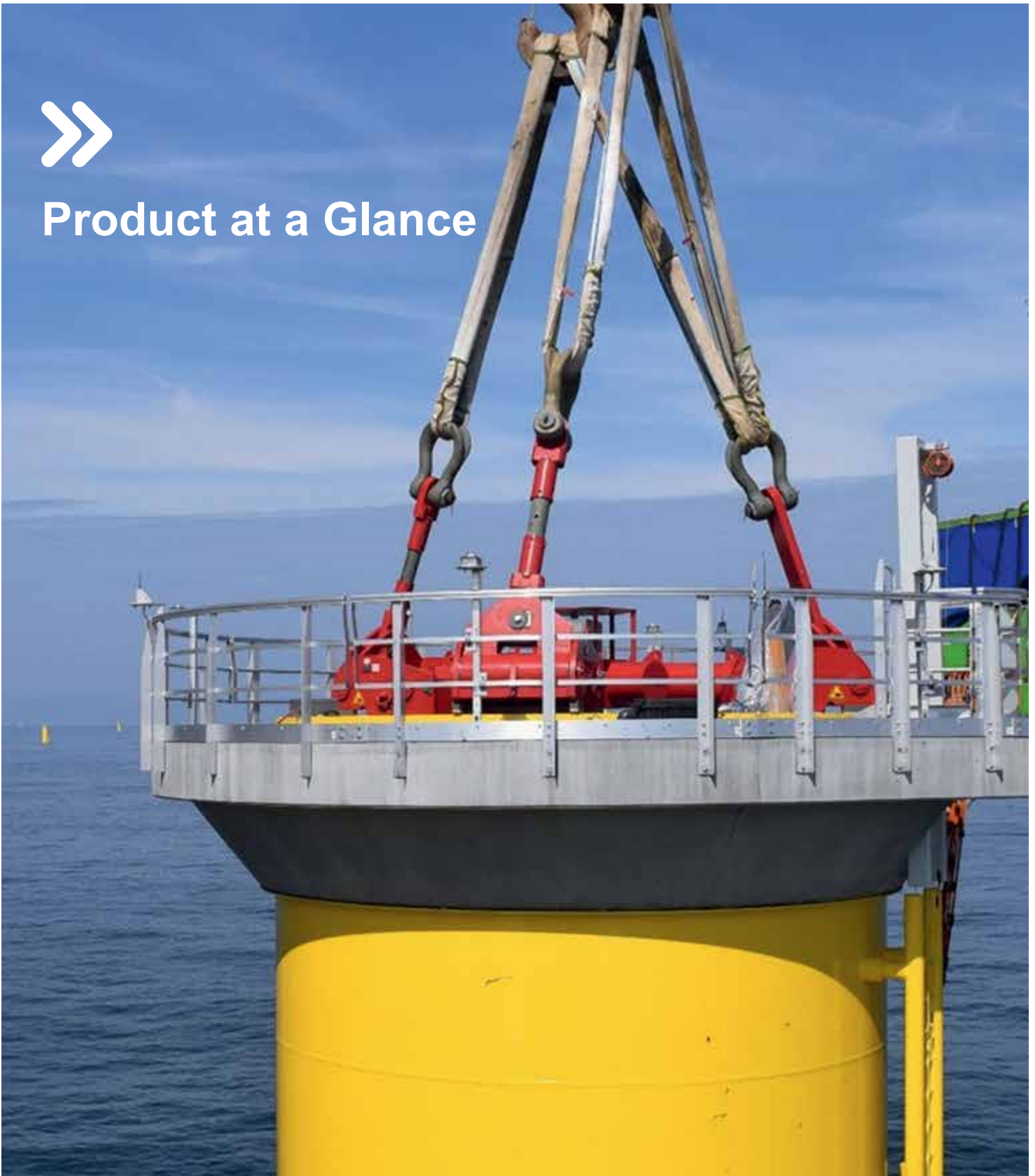


## MasterFlow 9500

Ultra-High Strength Grout  
for Offshore Wind Turbine  
Installations



## Product at a Glance



“Master Builder Solutions has successfully completed an extensive certification program in accordance with DNV-OS-C502 for their material MasterFlow 9500. It is considered a suitable material for use in load carrying grouted connections when applied in accordance with the approved procedures and within the stated application limitations.”

Andreas Lervik, Project Manager, DNV GL



# MasterFlow 9500: ExagROUT for Offshore Wind Turbine Installations

MasterFlow 9500 is an ultra-high strength and fatigue resistant cement based ExagROUT for offshore wind turbine installations – making wind energy projects more durable, time-efficient and secure.

Typically MasterFlow 9500 is used in the grouted connections of wind turbine foundations, e.g. between transition piece and monopile, in steel jackets and similar.

**The material has been especially formulated for large scale, pump applications:**

- Grouting of wind turbine installations where excellent fatigue resistance is required.
- Grouting under very harsh offshore conditions and temperatures as low as 0 °C.
- All void filling from 25 mm to 600 mm where high strength and fatigue resistance is important.

**Maintenance-free operation of wind farm**

MasterFlow 9500 exhibits long term durability and guarantees a fast, secure and cost effective installation of the offshore wind farm. Wind turbines are special – their safe and durable installation largely depends on the correct design and interaction of all components. Our MasterFlow ExagROUT’s high performance guarantees a long term and maintenance- free operation of the wind farm.

**Product benefits at a glance:**



**High fatigue resistance**  
Absorbing dynamic loads



**Rapid strength gain**  
Faster overall installation



**Secure installation**  
High early and final strengths

0 °C

**Cold weather**  
Applicable at temperatures down to 0 °C, allowing for working in shorter weather windows



**Proven high quality**  
Validated and certified by GL



**Excellent durability**  
Guaranteeing long term load transfer





# Excellent Strength even at Low Temperatures

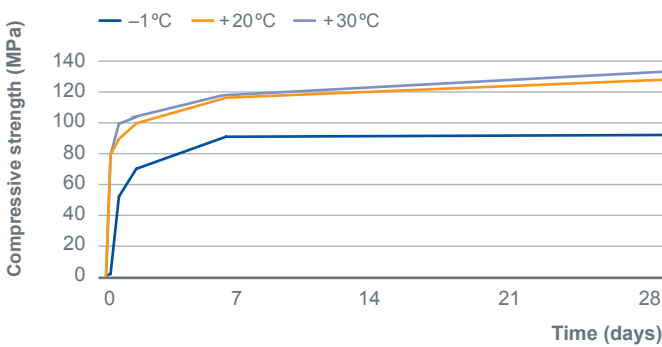
## Mechanical properties of MasterFlow 9500

### Compressive strength

The compressive strength of MasterFlow 9500 was tested in accordance with EN 12390-3, using variable size specimens ranging from 150 × 300 mm cylinders to 75 mm cubes and 40 × 40 × 160 mm prisms. Figure 1 shows the strength measurements of MasterFlow 9500 tested at different ages using 150 × 300 mm cylinders.

#### Compressive strength – 150 × 300 mm cylinders

Figure 1



### Flexural strength – tensile splitting

The flexural strength was measured in accordance with EN 196-1 on 40 × 40 × 160 mm prisms, while the splitting tensile strength was determined in accordance with EN 12390-5 on cylinders ø 100 × 200 mm. Results are shown in Table 1.

Table 1

Time	Flexural strength (MPa)	Tensile splitting strength (MPa)
28 days	18.4	8.6

### Static and dynamic modulus of elasticity

The static modulus of elasticity was measured on cylinders ø 100 × 200 mm cured 28 days in water in accordance with EN 13412. Results are shown in Table 2. Dynamic modulus of elasticity at cold temperatures was measured on prisms cured in water according to the guideline for the “protection and repair of concrete structures” of the German Committee of Reinforced Concrete (Rili-SIB DAfStb). The results are plotted in Figure 2.

#### Dynamic modulus of elasticity

Figure 2

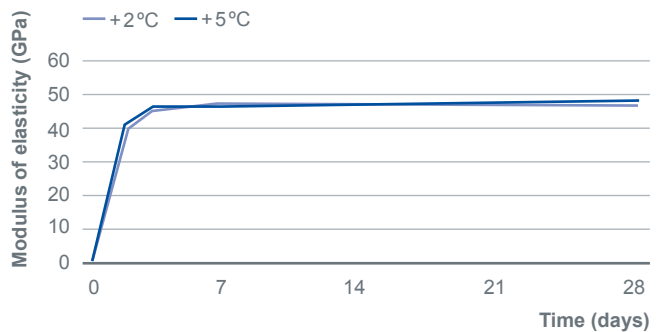


Table 2

Time	Modulus of elasticity (GPa)	Poisson's ratio
28 days	50.9	0.199

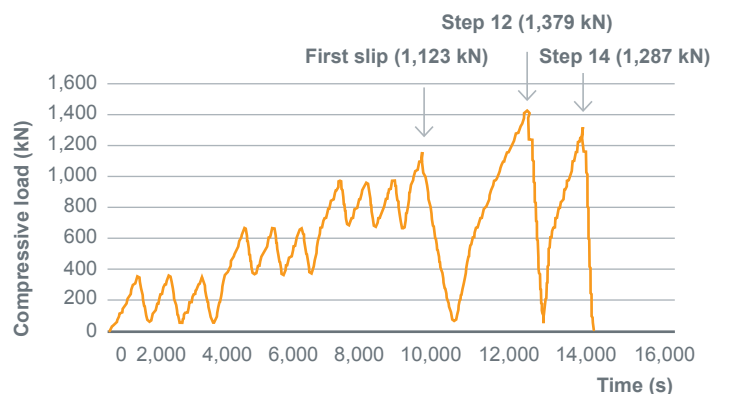


### Axial load capacity of grouted connections

A set of two concentric steel tubes – the annulus filled with MasterFlow 9500 – has been used to test the axial load capacity of the grouted connection under compression. The grouted connection has been exposed to pre-defined loads and relaxation before the compressive axial load has been increased until a first slip occurred. Thereafter the grouted connection was loaded and the axial load capacity is determined by the shear stresses. The results of the axial load capacity test are shown in Figure 3.

### Test results of compressive load capacity

Figure 3



MasterFlow 9500 exhibits a compressive axial load capacity which is more than twice as high as for other grout materials used under similar test conditions.



# Long Term Volume Stability

## Shrinkage compensated formulation

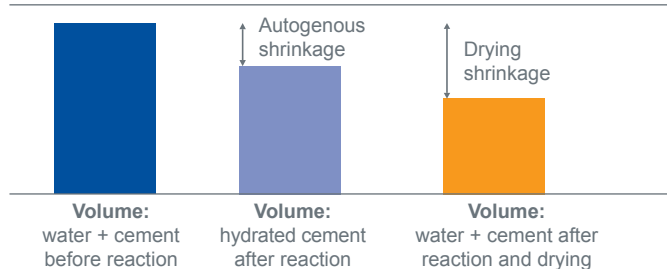
Volume stability is of utmost importance in the long term durability of foundations in offshore wind turbine installations. Verification of the autogenous shrinkage is therefore vital in the validation of the grouting material used in offshore grouted connections.

### What is autogenous shrinkage?

Autogenous shrinkage is the result of the chemical reaction between water and a cementitious material. The volume of the components before the reaction is typically larger than the volume of the end products i.e. hydrated cement (see Figure 4). Autogenous shrinkage can occur in wet conditions, in contradiction to drying shrinkage which occurs only in dry conditions.

### Measurement of volume change

Figure 4



Volume change before and after water and cement reaction

### Consequences of autogenous shrinkage

Autogenous shrinkage can result in debonding of the grout from the steel in grouted connections and consequently poor load transfer of the dynamic loads that act on the foundations in offshore wind turbine installations.

### Laboratory testing

Autogenous shrinkage was measured using a method developed at Aalborg University. After mixing MasterFlow 9500, corrugated plastic tubes, approximately 410 mm long and 30 mm

in diameter, were filled with the grout and then sealed by a plastic stopper in each end of the tube and placed in a temperature controlled room at 20°C. After final set, the length of each specimen was measured as a function of time, using micrometer gauge (Figure 5).

### Micrometer gauge to measure autogenous shrinkage

Figure 5

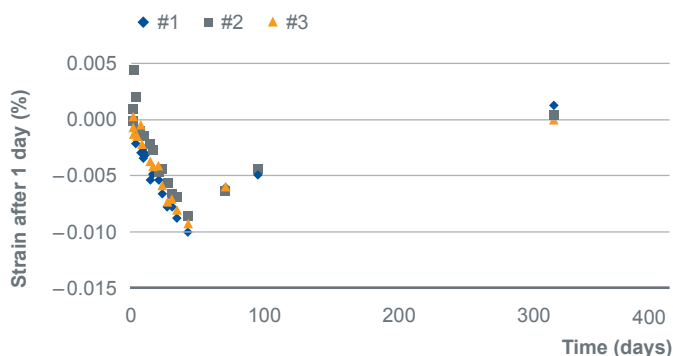


### Excellent laboratory results

Autogenous shrinkage results for MasterFlow 9500 can be found in Figure 6. Zero autogenous shrinkage is measured after approximately one year. The maximum autogenous shrinkage is only a fraction of other offshore grout materials in the market. Figure 6 also clearly shows the shrinkage compensation effect of MasterFlow 9500.

### Long term measurement of autogenous shrinkage

Figure 6





# Outstanding Fatigue Resistance

## Absorbing dynamic loads

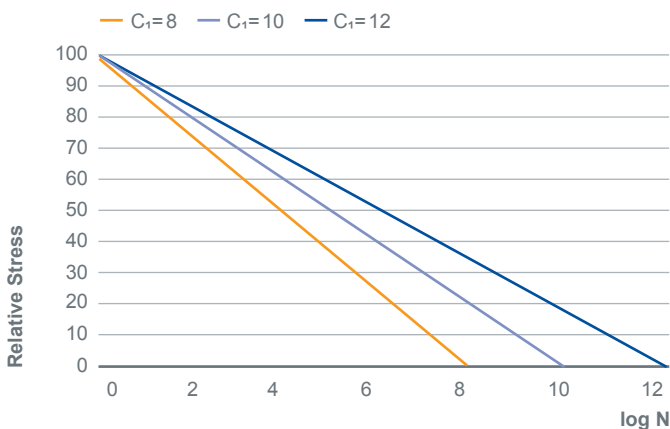
Fatigue resistance is the resistance to the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values are less than the ultimate stress limit and may be below the yield stress limit of the material.

### Occuring of fatigue

Fatigue occurs when a material is subjected to repeated loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form. Eventually a crack will reach a critical size, and the structure will suddenly fracture. The offshore design standard DNVGL-ST-C502 gives design guidelines for how to take into account maximum and minimum stress levels for fatigue life predictions (see Figure 7).

### Fatigue according DNVGL-ST-C502

Figure 7



### Let the numbers do the talking

Fatigue calculations are made according to the formulation

$$\log_{10} N = C_1 \cdot \frac{\left(1 - \frac{\sigma_{\max}}{C_5 \cdot f_{rd}}\right)}{\left(1 - \frac{\sigma_{\min}}{C_5 \cdot f_{rd}}\right)}$$

where:

- $C_1 = 12$  for structures in air
- $C_1 = 10$  for structures in water, and stress blocks having variation in the compression-compression range
- $C_1 = 8$  for structures in water, and stress blocks having variation in the compression-tension range
- $\sigma_{\max}$  = the numerically largest compressive stress, calculated as average within each stress-block
- $\sigma_{\min}$  = the numerically lowest compressive stress, calculated as average within each stress-block (for tension = 0)
- $C_5$  = strength reduction factor for the specific grout.  
 $C_5 = 0.85$  shall be taken for MasterFlow 9500

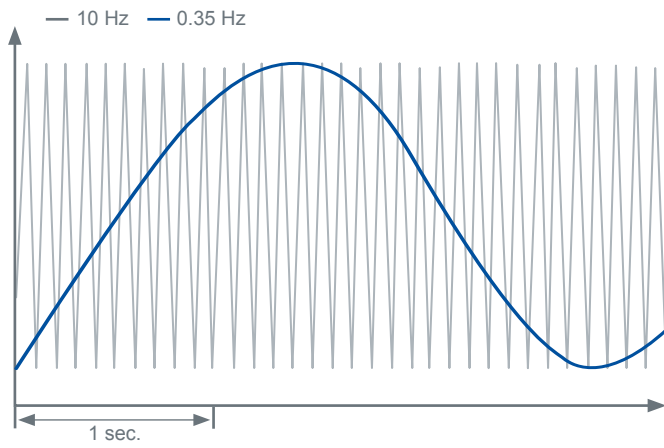


### Measurements under cyclic loading

The behavior of MasterFlow 9500 under cyclic loading was studied using cylindrical specimens, 60 mm in diameter and 120 mm high. The grout material has been tested for fatigue resistance in air and in water. Tests conducted in air were performed at high frequency (10 Hz), while tests in water were conducted at low frequency (0.35 Hz) in order to simulate the effect of wave actions on the foundations of offshore wind turbines (see also Figure 8).

### Fatigue resistance in air and in water

Figure 8

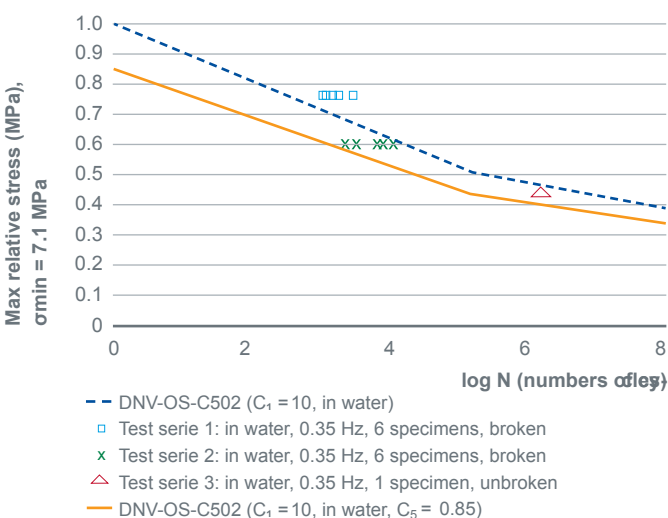


### Results as good as for reinforced concrete

The observed number of cycles to failure in the tests under cyclic loading corresponds well with the prediction according to DNVGL-ST-C502 (Figure 9). It can be concluded that MasterFlow 9500 shows a performance under cyclic loading that is as good as for reinforced concrete. Based on the tests, it is concluded that the design for fatigue can be carried out using formulations for fatigue life prediction in DNVGL-ST-C502 for reinforced concrete.

### Fatigue life prediction

Figure 9



Our reference in the Liverpool Bay (United Kingdom) – Gwynt Y Môr: 160 turbines installed on monopile transition piece foundations. Grouting works well continued at temperatures as low as 2°C  
© FoundOcean Ltd



Our reference in the Irish Sea (United Kingdom) – West of Duddon Sands:  
108 turbines, installed on monopile transition piece foundations.  
Foundation installation and grouting in a record time of just 6 months  
© FoundOcean Ltd



# Master Builders Solutions

The Master Builders Solutions brand brings all of our expertise together to create chemical solutions for new construction, maintenance, repair and renovation of structures. Master Builders Solutions is built on the experience gained from more than a century in the construction industry. The know-how and experience of a global community of construction experts form the core of Master Builders Solutions.

We combine the right elements from our portfolio to solve your specific construction challenges. We collaborate across areas of expertise and regions and draw on the experience gained from countless construction projects worldwide. We leverage global technologies, as well as our in-depth knowledge of local building needs, to develop innovations that help make you more successful and drive sustainable construction.

The comprehensive portfolio under the Master Builders Solutions brand encompasses concrete admixtures, cement additives, solutions for underground construction, waterproofing solutions, sealants, concrete repair & protection solutions, performance grouts, performance flooring solutions and solutions for on- and offshore wind energy.

## Our comprehensive portfolio

- Concrete admixtures
- Cement additives
- Chemical solutions for underground construction
- Waterproofing solutions
- Sealants
- Concrete repair and protection solutions
- Performance grouts
- Wind turbine grouts
- Performance flooring solutions

