

Masterflow[®] 9500

Fatigue resistant ExagROUT - Study results



Masterflow® 9500



ExagROUT for offshore wind turbine installations

Masterflow 9500 is a new generation of ultra high strength, high modulus, fatigue resistant cement based ExagROUT for grouting offshore wind turbine installations. The material has been especially formulated for large scale, pump applications:

- Grouting of wind turbine installations where excellent fatigue resistance is required, e.g. in grouted connections in monopile, tripod or jacket type foundations.
- Grouting under very harsh conditions, e.g. offshore applications or below water grouting, at temperatures as low as 2°C.
- All void filling from 25 mm to 200 mm where high strength and fatigue resistance is important, e.g. with gravity based foundations.

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 – and require a high performance **Masterflow** ExagROUT to guarantee long term and maintenance free operation of the wind farm.

BASF helps the wind industry to be more successful by better understanding the needs of our partners and reducing the risks involved in the construction and exploration of modern wind farms. Managing risks means for BASF Construction Chemicals amongst others:

- **Masterflow 9500** ExagROUT installed by BASF Licensed Contractors
- Independent documentation of the material properties
- Detailed installation methods as part of the Quality Assurance
- Validation and “Fit for Purpose” verification by DNV
- Extended warranties for correctly installed and operated wind farms
- Compulsory training of BASF Licensed Contractors

Masterflow 9500 ExagROUT for offshore wind turbine installations:



Excellent durability:

- High fatigue resistance, absorbing dynamic loads
- Zero autogenous shrinkage; volume stable
- High flexural strength, even without the addition of fibres
- Freeze/Thaw resistant
- Very low porosity and water absorption



Secure installation:

- Ultra-high axial load capacity
- Excellent long term load transfer
- Validated by Det Norske Veritas (DNV)
- High ultimate strengths
- Installation by BASF licensed contractors



Fast and cost effective installation:

- Rapid strength build-up, even at cold temperatures
- Short overall installation times and earlier operation of the wind farm
- Faster energy production, earlier return on investment safeguard project completion on time



Product validation

BASF has developed a specific grout, **Masterflow 9500**, for application in offshore wind turbine installations. Typically the product is used in the grouted connections of wind turbine foundations, e.g. between transition piece and monopile, in steel jackets and similar.

BASF has therefore instructed Det Norske Veritas (DNV) to verify **Masterflow 9500** for use in offshore wind turbine installations. Throughout the validation process, DNV has conducted the following activities:

1. Validation and acceptance of testing methodology, procedures and extent
2. Evaluation and acceptance of Aalborg University DCE Laboratory as an external, independent test laboratory
3. Evaluation, witnessing and acceptance of mock-up application and large scale field pumping trials
4. Audit, evaluation and acceptance of grout manufacturing equipment and facilities
5. Audit of BASF laboratory and factory production/quality control
6. Evaluation and acceptance of the independent laboratory test results and large scale grout pumping trials
7. Evaluation of grout suitability in offshore applications such as grouted connections in offshore wind turbine foundations
8. Acceptance of TUM (Technische Universität München) as qualified test laboratory
9. Evaluation and acceptance of laboratory tests carried out at TUM for grout at +2 and +5°C

A Statement of Compliance is issued by DNV based on the above verification programme. The Statement of compliance is a written assurance that **Masterflow 9500** conforms to specific strength, durability and functional requirements.

DNV – Conclusions and recommendations

- The verification programme for **Masterflow 9500** has been successfully completed by DNV according the defined scope of work
- Fatigue life has been tested and results compared with predictions for fatigue life in accordance with DNV-OS-C502 for equivalent stress conditions
- **Masterflow 9500** shows as good a performance under cyclic loading as reinforced concrete
- The ultra high modulus of elasticity may also give benefits with a stiffening effect
- The results of the mock-up test confirm the functional properties of **Masterflow 9500** and indicate that the grout is suitable for the intended applications
- **Masterflow 9500** exhibits very good pumpability and flowability over a long period of time. The grout is capable to be pumped through a 2 in. hose over 200 m length and 20 m elevation

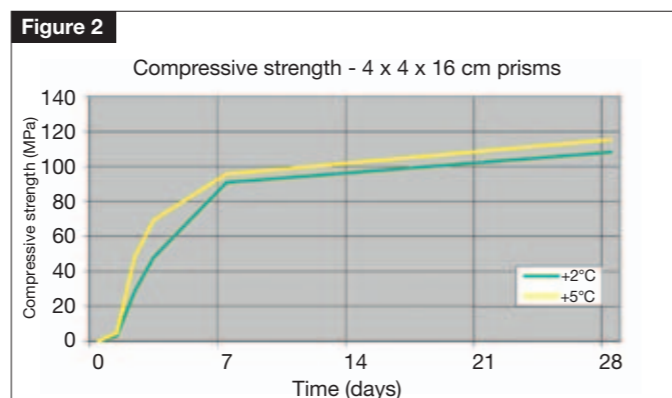
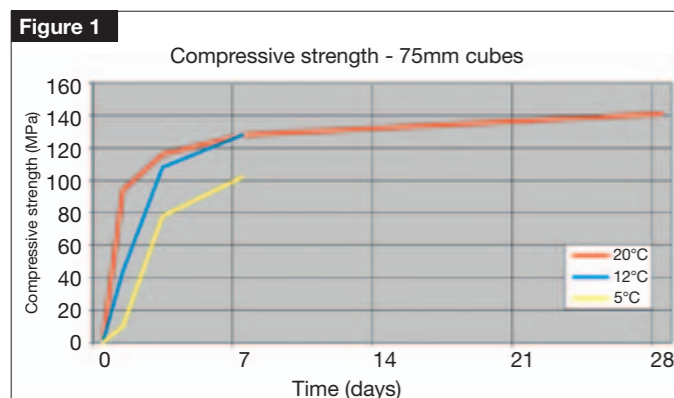


Masterflow 9500®
Statement of compliance
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Masterflow® 9500: Mechanical properties

Compressive strength

Compressive strength of **Masterflow 9500** was tested in accordance with EN 12390-3, using 75 mm cubes. At each testing age 3 cubes were tested. The compressive strengths are plotted as a function of age in Figure 1. Strength development at cold temperatures was determined in accordance with EN196-1. The results for **Masterflow 9500** tested at +2°C and +5°C are shown in Figure 2.



Flexural strength – Tensile splitting strength

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

Table 1

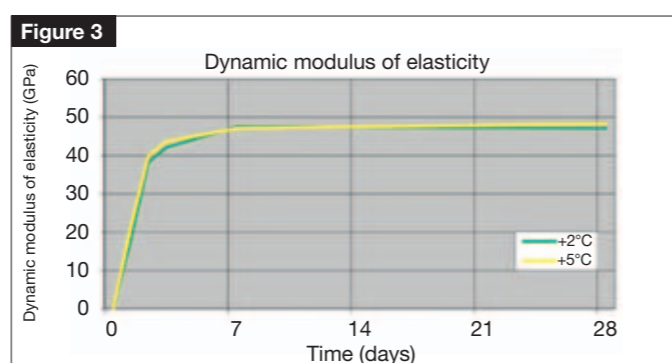
Time	Flexural Strength (Mpa)	Tensile splitting strength (Mpa)
28 days	18.4	8.6

Table 2

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

Static and dynamic modulus of elasticity

The static modulus of elasticity was measured on cylinders ø 100 x 200 mm cured 28 days in water in accordance with to EN 13412. Results are shown in Table 2. Dynamic modulus of elasticity at cold temperatures was measured on prisms cured in water according 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 3.



Autogenous shrinkage

What is autogenous shrinkage?

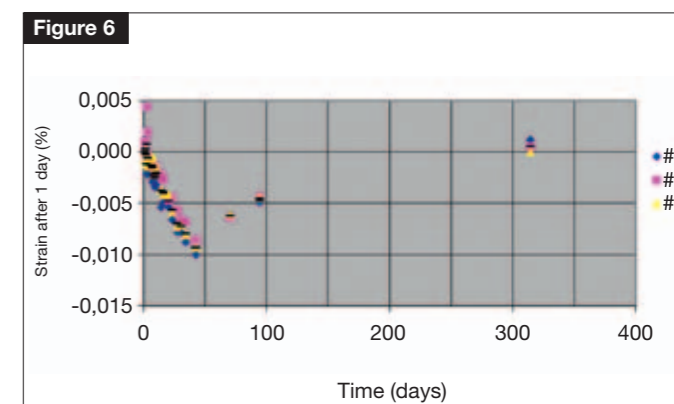
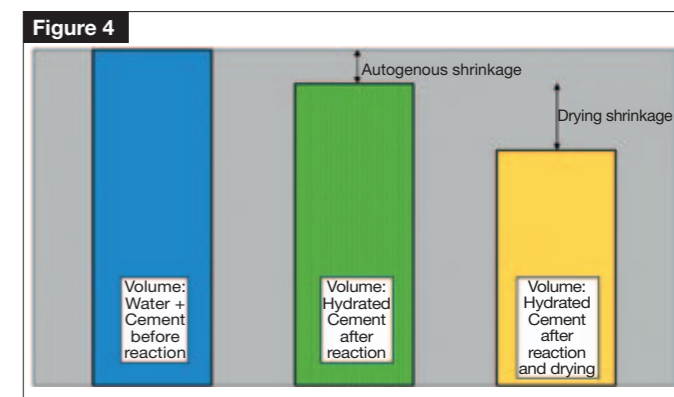
Autogenous shrinkage is the result of the chemical reaction between water and a cementitious material. The volume of the components before the reaction is typically larger as the volume of the end products i.e. hydrated cement (see Figure 4.). Autogenous shrinkage can occur in wet conditions, in contradiction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

Autogenous shrinkage can result in de-bonding 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.

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.

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 a micrometer gauge, cf. Figure 5.

Autogenous shrinkage results found in the technical literature most often refer to measurements starting at an age of one day when the specimens are de-moulded. Figure 6 shows the autogenous shrinkage measured over time starting at the age of one day. Zero autogenous shrinkage is measured after approximately one year.



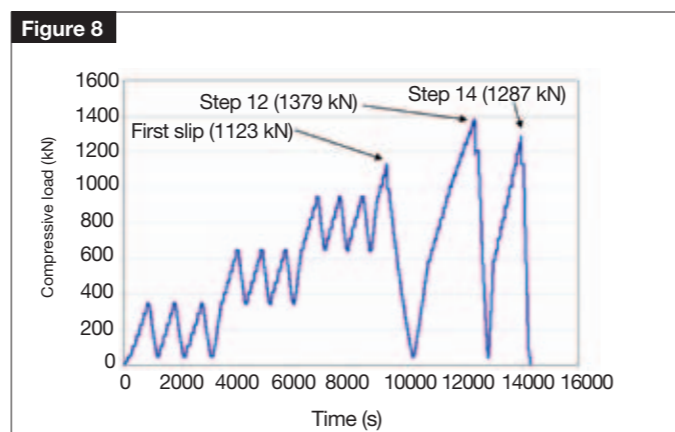
Masterflow® 9500: Mechanical properties

Axial load capacity of grouted connection

The main purpose of this test is to determine the maximum compressive axial force required to produce a slip on the interface between the steel surface and the grout. This force will be defined as the failure load or the ultimate resistance capacity of the connection against static compressive axial loading.

A set of two concentric steel tubes are used for making test specimens. The annulus between the inner and outer tubular has been filled with **Masterflow 9500**. (see Figure 7) A compressive load of 50 kN has been applied to the grouted connection and increased in steps of 60 kN. 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. At this point the grouted connection did not manage to sustain the compressive load. After almost complete relaxation, loads were re-applied. As opposed to the loading process prior to the first slip, where the adhesion of the grout to the steel surfaces determines the axial load capacity, the loading process in subsequent load testing is determined by shear forces between the grout and the steel. Compressive load versus time recorded during the test is presented in Figure 8.

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

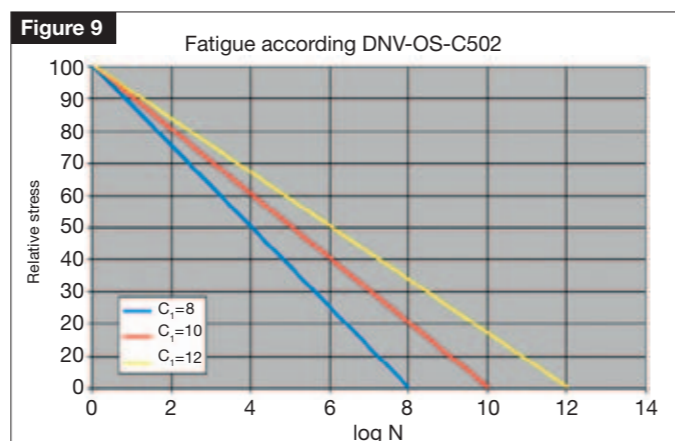


Fatigue behaviour

Fatigue resistance is the resistance to the progressive and localised 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.

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 DNV-OS-C502 gives design guidelines for how to take into account maximum and minimum stress levels for fatigue life predictions. (see Figure 9)



Fatigue calculations are made according the formulation

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

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

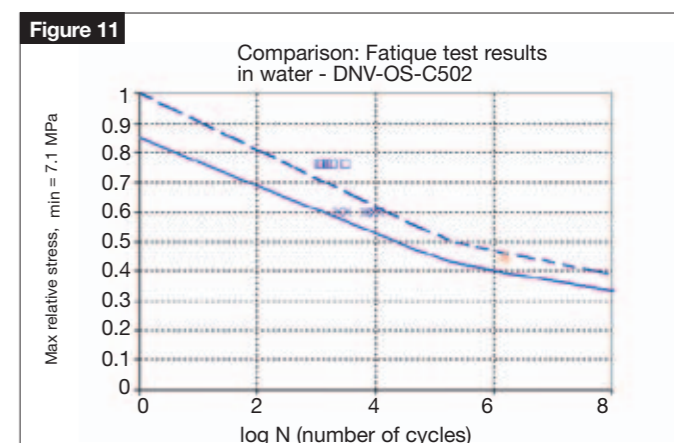
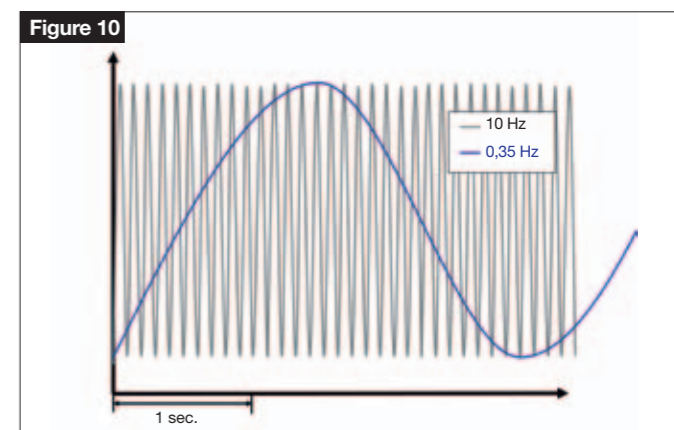
\max = the numerically largest compressive stress, calculated as average within each stress-block

\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**

The behaviour 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 10)

The observed number of cycles to failure in the tests under cyclic loading corresponds well with the prediction according DNV-OS-C502 (Figure 11). 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 DNV-OS-C502 for reinforced concrete.



- DNV-OS-C502 ($C_1=10$, in water)
- Test serie 1: in water, 0.35 Hz, 6 specimens, broken
- x Test serie 2: in water, 0.35 Hz, 6 specimens, broken
- △ Test serie 3: in water, 0.35 Hz, 1 specimens, unbroken
- DNV-OS-C502 ($C_1=10$, in water, $C_5=0.85$)

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