MasterFlow 9500

Ultra-High Strength Grout for Offshore Wind Turbine Installations

A brand of MBCC GROUP

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

Certification of MasterFlow 9500

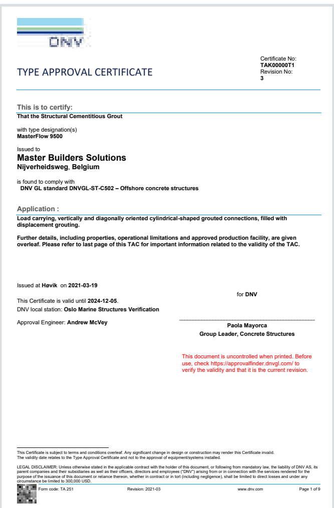
Master Builders Solutions helps the wind industry to be more successful by better understanding the needs of our partners and reducing the risks involved in the construction and exploration of modern wind farms.

Master Builder Solutions has instructed DNV GL to verify MasterFlow 9500 in accordance with the guideline DNVGL-ST-C502, for use in offshore wind turbine installations. Throughout the validation process, DNV GL has validated and witnessed a whole number of laboratory testing, mock-up trials and verified installation guidelines and Quality Assurance documents.

Several external, independent laboratories were used throughout the validation process, such as

- Aalborg University DCE Laboratory, Denmark
- DNV GL's own testing laboratory in Høvik, Norway
- Technische Universität München, Germany
- Applus, LGAI Technical Center S.A., Spain

An audit of the grout manufacturing equipment and facilities, and factory production control by representatives of DNV GL, was successfully concluded with excellent notes.



DNV

TYPE APPROVAL CERTIFICATE

Certificate No:
TAK00000T1
Revision No:
3

This is to certify:
That the Structural Cementitious Grout

with type designation(s)
MasterFlow 9500

Issued to
Master Builders Solutions
Nijverheidsweg, Belgium

is found to comply with
DNV GL standard DNVGL-ST-C502 – Offshore concrete structures

Application :
Load carrying, vertically and diagonally oriented cylindrical-shaped grouted connections, filled with displacement grouting.

Further details, including properties, operational limitations and approved production facility, are given overleaf. Please refer to last page of this TAC for important information related to the validity of the TAC.

Issued at **Høvik** on **2021-03-19**

This Certificate is valid until **2024-12-05**.
DNV local station: **Oslo Marine Structures Verification**

Approval Engineer: **Andrew McVey**

for **DNV**

Paola Mayorca
Group Leader, Concrete Structures

This document is uncontrolled when printed. Before use, check https://approvalfinder.dnvgl.com/ to verify the validity and that it is the current revision.

This Certificate is subject to terms and conditions overleaf. Any significant change in design or construction may render this Certificate invalid.
The validity date relates to the Type Approval Certificate and not to the approval of equipment/systems installed.

LEGAL DISCLAIMER: Unless otherwise stated in the applicable contract with the holder of this document, or following from mandatory law, the liability of DNV AS, its parent companies and their subsidiaries as well as their officers, directors and employees ("DNV") arising from or in connection with the services rendered for the purpose of the issuance of this document or reliance thereon, whether in contract or in tort (including negligence), shall be limited to direct losses and under any circumstance be limited to 300,000 USD.

Form code: TA 251 Revision: 2021-03 www.dnv.com Page 1 of 9

DNV GL – conclusions and recommendations

- The verification programme for MasterFlow 9500 has been successfully completed by DNV GL according to the defined scope of work
- Fatigue life has been tested and results compared with predictions for fatigue life in accordance with DNVGL-ST-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 inch hose over 200 m length and 20 m elevation
- MasterFlow 9500 can be installed at temperatures down to 0 °C.

A certificate is issued by DNV GL based on the above verification programme. The certificate is a written assurance that MasterFlow 9500 conforms to specific strength, durability and functional requirements.

Excellent Strength even at Low Temperatures

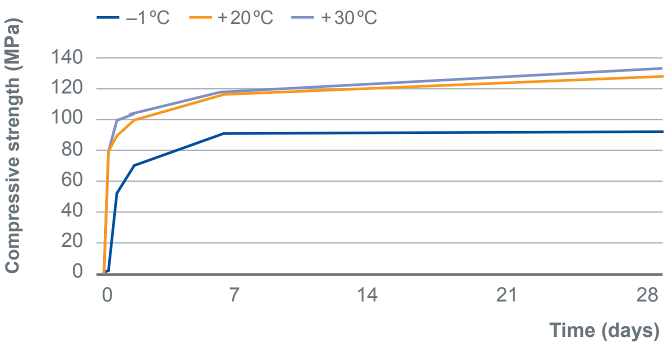
Mechanical properties of MasterFlow 9500

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 elastictiy

Figure 2

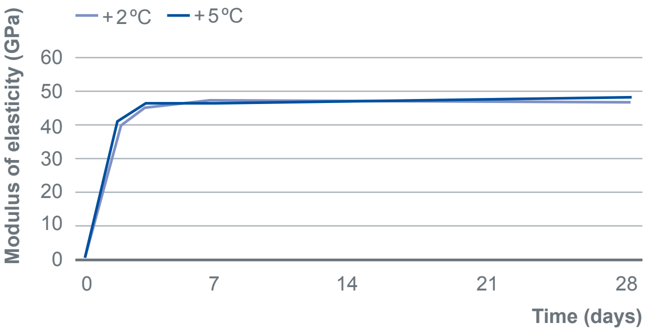


Table 2

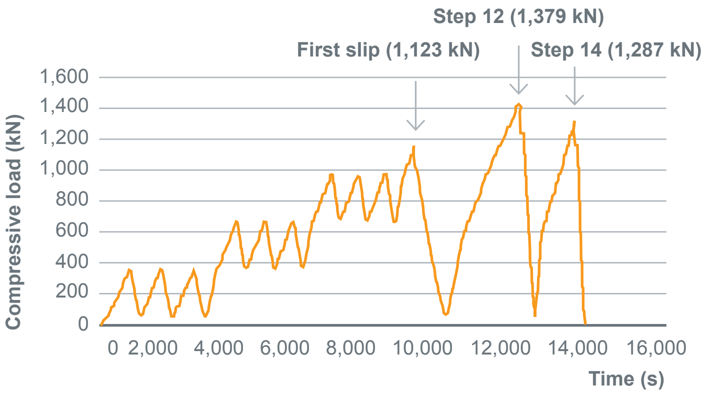
Time	Modulus of elasticity (GPa)	Poisson’s ratio
28 days	50.9	0.199

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

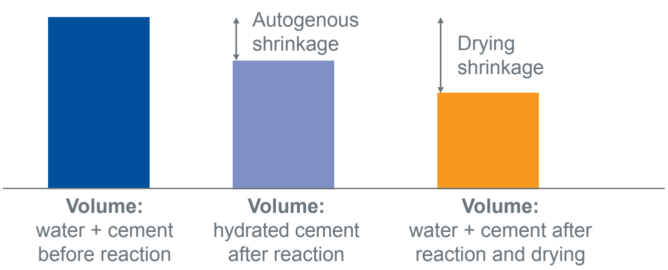
Volume stability is of utmost importance in the long term durability of foundations in offshore wind turbine installations. Verification of the autogenous shrinkage is therefore vital in the validation of the grouting material used in offshore grouted connections.

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

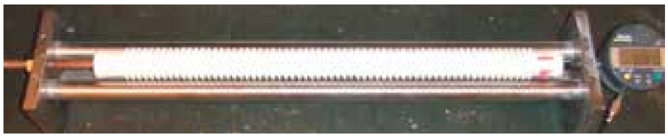
Autogenous shrinkage can result in debonding of the grout from the steel in grouted connections and consequently poor load transfer of the dynamic loads that act on the foundations in offshore wind turbine installations.

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

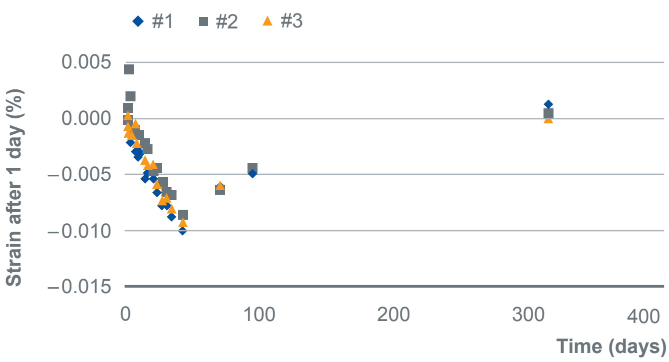


Excellent laboratory results

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

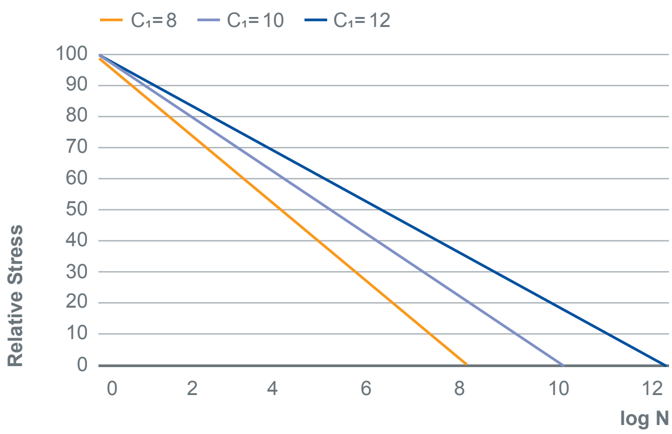
Fatigue resistance is the resistance to the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values are less than the ultimate stress limit and may be below the yield stress limit of the material.

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)

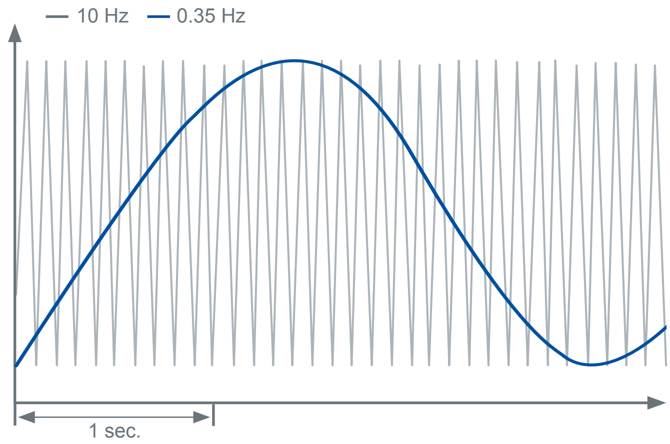
C_5 = strength reduction factor for the specific grout. C_5= 0.85 shall be taken for MasterFlow 9500

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

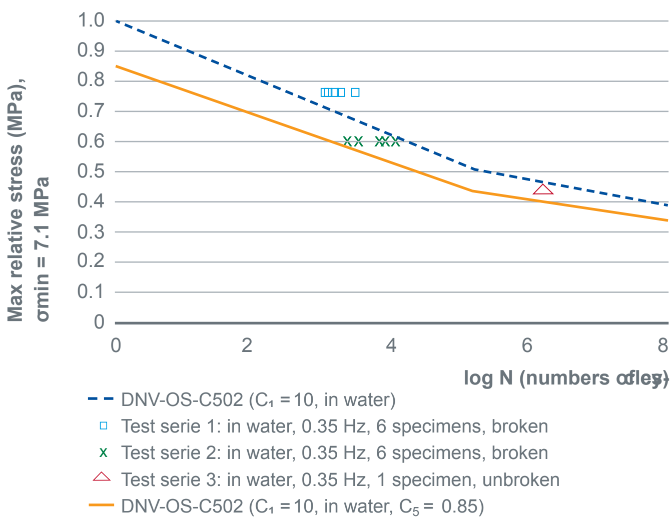


Results as good as for reinforced concrete

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.

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

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

Master Builders Solutions for the Construction Industry

MasterAir
Complete solutions for air entrained concrete

MasterBrace
Solutions for concrete strengthening

MasterCast
Solutions for the manufactured concrete product industry

MasterCem
Solutions for cement manufacture

MasterEase
Low viscosity for high performance concrete

MasterEmaco
Solutions for concrete repair

MasterFinish
Solutions for formwork treatment and surface improvement

MasterFlow
Solutions for precision grouting

MasterFiber
Comprehensive solutions for fiber reinforced concrete

MasterGlenium
Solutions for high performance concrete

MasterInject
Solutions for concrete injection

MasterKure
Solutions for concrete curing

MasterLife
Solutions for enhanced durability

MasterMatrix
Advanced rheology control for concrete

MasterPel
Solutions for hydrophobization, anti-efflorescence and surface protection

MasterPolyheed
Solutions for mid-range concrete

MasterPozzolith
Solutions for water-reduced concrete

MasterProtect
Solutions for concrete protection

MasterRheobuild
Solutions for high strength concrete

MasterRoc
Solutions for underground construction

MasterSeal
Solutions for waterproofing and sealing

MasterSet
Solutions for set control

MasterSphere
Solutions for guaranteed freeze-thaw resistance

MasterSuna
Solutions for sand and gravel in concrete

MasterSure
Solutions for extraordinary workability retention

MasterTop
Solutions for industrial and commercial floors

Master X-Seed
Advanced accelerator solutions for concrete

Ucrete
Flooring solutions for harsh environments

QUANTIFIED SUSTAINABLE BENEFITS ADVANCED CHEMISTRY BY MASTER BUILDERS SOLUTIONS

Let the numbers do the talking: We have portrayed some of our most eco-efficient product solutions for concrete and precast production, construction, civil engineering, and flooring.

sustainability.master-builders-solutions.com

Master Builders Solutions
Product Management
c/o PCI Augsburg GmbH
Piccardstrasse 11
86159 Augsburg, Germany
www.master-builders-solutions.com

Master Builders Solutions UK Ltd
19 Broad Ground Road, Lakeside,
Redditch Worcestershire, B98 8YP, United Kingdom
P +44 1527 512 255, F +44 1527 503 576
redditchcom@mbcc-group.com
www.master-builders-solutions.com

Master Builders Solutions Belgium nv
Nijverheidsweg 89
3945 Ham, Belgium
P +31 11 340 431
mbs-cc-be@mbcc-group.com
www.master-builders-solutions.com

MBS-07-2022-WTG-0036-EN