# Fatigue of alternative material -comparison of R=-1 at ambient and +60° (WMC results)-

**OB_TG3_R026 rev. 001**
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***Confidential***

*TG 3*

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Change record

| Issue/revision | date | pages | Summary of changes |
|---|---|---|---|
| first version | 8/2/6 | 7 | first version |
| revision 1 | 8/2/6 | 7 | minor textual revisions |

# Introduction

This document describes the fatigue results obtained from the MD4 (alternative resin system) with geometry R0400 (standard OB MD coupon). Fatigue tests were done at R=-1. The results are also compared with the results from the standard laminate.
These tests were done in the framework of Task Group 3, Work Package 9 For a detailed description of work in this task group, see [1]. These results add to the work reported in e.g. [2].

# Test set-up

All coupons tested at +60° were standard MD R0400 coupons, tested at the 100 kN Schenck. The test set-up is depicted in Fig. 1. Most of the coupons at ambient conditions were tested at the same machine. For the +60°-tests, a temporary climate chamber was built around the grips. A heating element, temperature sensor and controller were used to maintain the temperature at the desired value. An internal fan ensured maximum uniformity of the temperature distribution within the chamber. The accuracy of this set-up was typically 60°C ±2°C for the temperature of the specimen, measured near the grips. Temperature was measured using one or two thermocouples. Typically, one temperature sensor was mounted at the side and centre of the gauge length and is representative for the air temperature in the chamber. The other temperature sensor was mounted at the prescribed location near the tab in the lower grip, which is the moving grip. This grip is usually slightly warmer than the non-moving grip because of the heat from the oil. Therefore, the chamber temperature was controlled to a value lower than +60°, so that the temperature measured on the coupon near the lower grip did not exceed +60°C

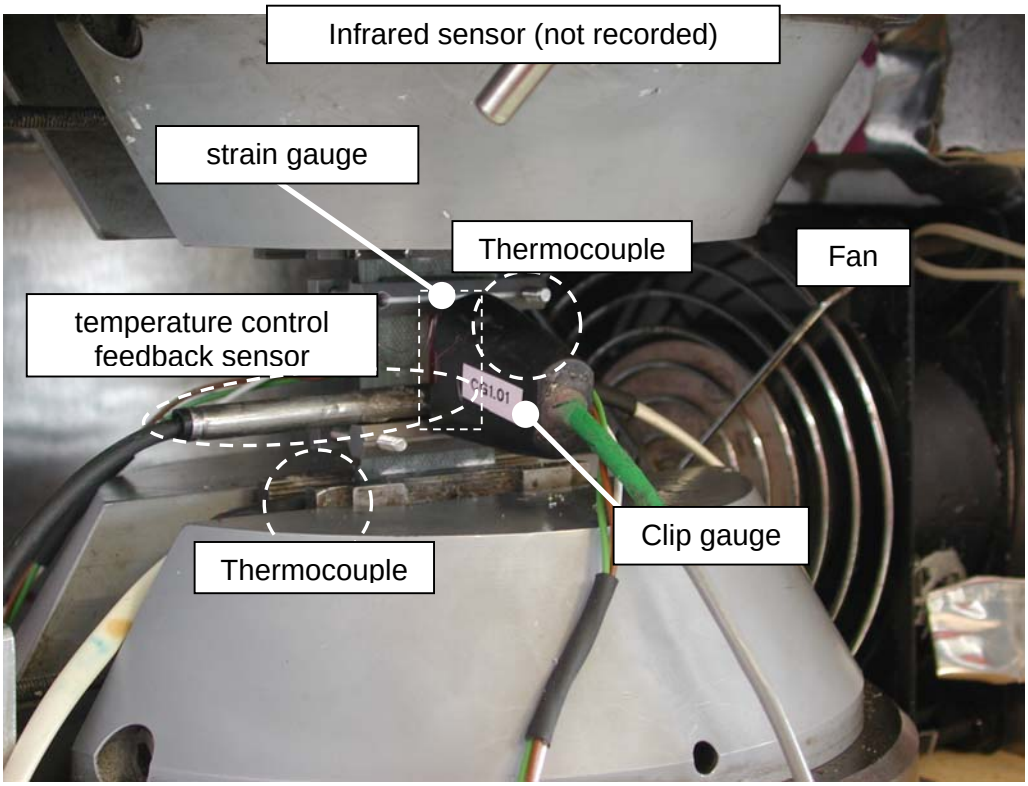


Figure 1: Test set-up

Standard OB load levels, and associated frequencies were used. However, at the higher load levels, tests were also carried out at half the prescribed frequency.

Prior to the fatigue tests, accurate strain measurements were done during a slow loading cycle (0.02 Hz). These measurements were used for determination of initial modulus. The coupons were equipped with both strain gauges and clip-gauges in a back-to-back configuration. Measurements from all channels were recorded using in-house developed measurement software [3] throughout the fatigue tests at intervals of 10 to 1000 cycles. The slow cycle was done at elevated temperature compared to ambient temperature, but in practice, the temperature was lower than +60°. During the first part of the fatigue test, the temperature rise due to grip friction caused the temperature rise required for the test.
The sensors were tared before closing of the non-moving grip, at elevated temperature. For one coupon (GEV307_R0400_0026), the slow cycle was performed at room temperature and elevated temperature, to investigate the influence of temperature on the strain readings. The moduli at elevated temperatures were typically 2 GPa lower than at room temperature.
After completion of the tests, the failed coupons were photographed and archived for future reference. The measurement files were processed and analysed, which is reported below.

# Results and Discussion

The test results are available from OptiDAT [4]. S-N curves for the reference and +60°C tests are shown in Fig. 2 With respect to reference conditions, the R=-1 fatigue performance at +60° was considerably worse. This is in agreement with the deteriorated +60°C fatigue lives found for the UD material in previous tests [2].

Table 1 shows, for all tested coupons, the most important results. The S-N data are plotted in the double-logarithmic diagram of figure 2. Compared to the reference material, the coupons with alternative resin have a slightly higher fatigue life. However, coupons tested at +60°C exhibit significantly shorter fatigue lives. The difference with ambient conditions typically is more than a decade for the higher load levels. For lower load levels, the influence of temperature seems to diminish, but fatigue lives at level 3 are still half a decade below the ambient condition data. Modulus at elevated temperature was approximately 1.5-2 GPa (7%) lower than at room temperature.

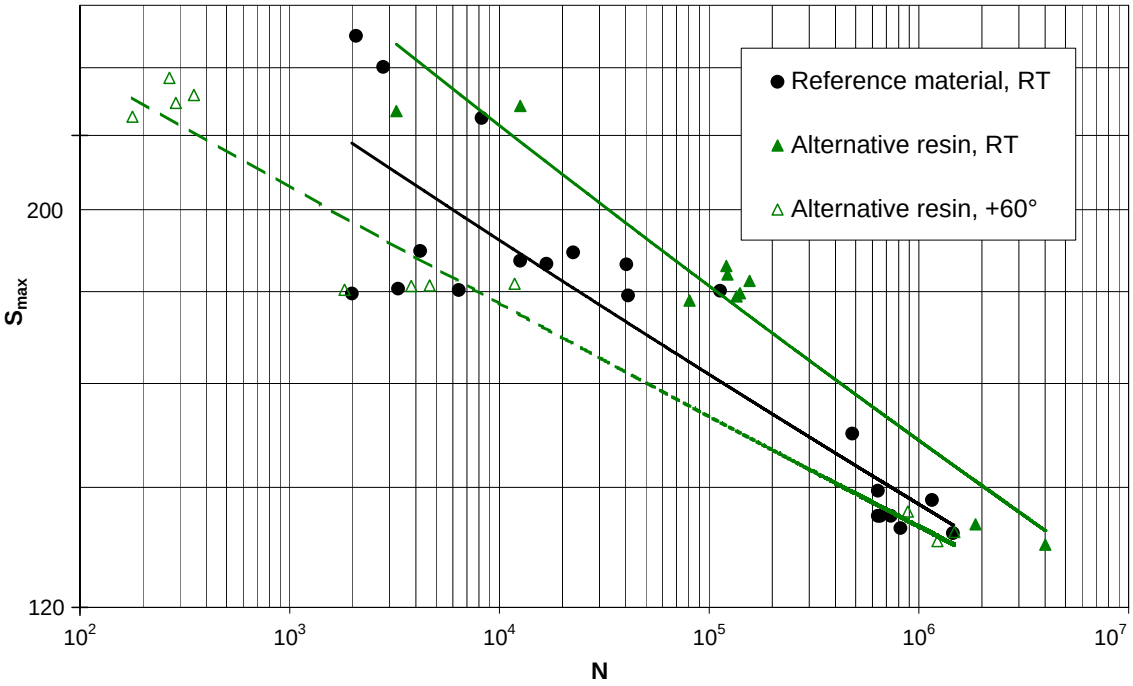


Figure 2: S-N data of reference (alternative) materials +60°C tests (R=-1)

**Table 1: Test results**

| Type | Coupon | $S_{max}$ | N | f | max temp during fatigue | $E_{it}$ | $E_{ic}$ | $E_{t, avg}$ | $E_{c, avg}$ |
|---|---|---|---|---|---|---|---|---|---|
| *Reference material* | *GEV207_R0400_0875* | 189 | 22500 | 1.44 | | | | | |
| | *0479* | 180 | 1980 | 1.44 | | 26.4 | 25.1 | | |
| | *GEV207_R0400_0472* | 132 | 1452093 | 2.57 | | | | | |
| | *GEV207_R0400_0481* | 181 | 3288 | 1.44 | | | | | |
| | *GEV207_R0400_0799* | 186 | 40297 | 1.44 | | | | | |
| | *GEV207_R0400_0807* | 190 | 4191 | 1.44 | | | | | |
| | *GEV207_R0400_0825* | 139 | 637298 | 2.57 | | | | | |
| | *GEV207_R0400_0829* | 240 | 2793 | 0.88 | | | | | |
| | *GEV207_R0400_0847* | 187 | 12581 | 1.44 | | | | | |
| | *GEV207_R0400_0499* | 179 | 41120 | 1.44 | | 27.7 | 26.7 | | |
| | *GEV207_R0400_0488* | 180 | 112810 | 1.44 | | 27.7 | | *27.3* | *26.5* |
| | *GEV207_R0400_0485* | 180 | 6412 | 1.44 | | 26.7 | 25.1 | | |
| | *GEV207_R0400_0507* | 133 | 817473 | 2.57 | | | 26.9 | | |
| | *GEV207_R0400_0567* | 187 | 16768 | 1.44 | | 30.9 | 30.3 | | |
| | *GEV207_R0400_0783* | 138 | 1155325 | 2.57 | | | | | |
| | *GEV207_R0400_0113* | 135 | 735186 | 2.57 | | 26.9 | 26.5 | | |
| | *GEV207_R0400_0112* | 135 | 655532 | 2.57 | | 28.3 | 27.9 | | |
| | *GEV207_R0400_0111* | 150 | 481189 | 2.08 | | 27.3 | 26.8 | | |
| | *GEV207_R0400_0110* | 250 | 2074 | 0.75 | | 26.0 | 25.1 | | |
| | *GEV207_R0400_0109* | 225 | 8234 | 0.93 | | 26.4 | 25.5 | | |
| | *GEV207_R0400_0108* | 135 | 637851 | 2.57 | | 26.6 | 26.2 | | |
| *Alternative, RT* | *GEV307_R0400_0002* | 134 | 1861829 | 2.57 | 26 | 29.0 | 29.2 | | |
| | *GEV307_R0400_0006* | 184 | 122357 | 1.44 | | | | | |
| | *GEV307_R0400_0008* | 179 | 135082 | 1.44 | | 28.5 | 28.7 | | |
| | *GEV307_R0400_0009* | 130 | 4002788 | 2.57 | 33 | 28.4 | 28.7 | | |
| | *GEV307_R0400_0010* | 180 | 140168 | 1.44 | 29 | 26.4 | 26.8 | *28.3* | *28.6* |
| | *GEV307_R0400_0012* | 227 | 3227 | 0.88 | | 27.9 | | | |
| | *GEV307_R0400_0014* | 228 | 12575 | 0.88 | 23 | 28.5 | 28.7 | | |
| | *GEV307_R0400_0016* | 186 | 120841 | 1.44 | 21 | 29.1 | 29.2 | | |
| | *GEV307_R0400_0018* | 178 | 80680 | 1.44 | | 28.0 | 28.3 | | |
| | *GEV307_R0400_0023* | 183 | 155789 | 1.44 | 25 | 28.7 | 29.0 | | |
| *Alternative, 60C* | *GEV307_R0400_0025* | 132 | 1477579 | 2.57 | 63 | 26.7 | 26.8 | | |
| | *GEV307_R0400_0026* | 131 | 1226203 | 2.57 | 62 | 25.4 | 25.3 | | |
| | *GEV307_R0400_0028* | 237 | 267 | 0.44* | 61 | 27.4 | 27.4 | | |
| | *GEV307_R0400_0029* | 225 | 178 | 0.88 | >70 | 27.4 | 26.4 | | |
| | *GEV307_R0400_0030* | 180 | 1828 | 1.44 | 61 | 26.3 | 27.3 | | |
| | *GEV307_R0400_0031* | 181 | 4647 | 0.72* | 60 | 27.7 | 27.8 | *26.7* | *26.8* |
| | *GEV307_R0400_0032* | 232 | 350 | 0.44* | 61 | 26.9 | 27.0 | | |
| | *GEV307_R0400_0033* | 182 | 11829 | 0.72* | 62.9 | 26.7 | 26.8 | | |
| | *GEV307_R0400_0034* | 229 | 287 | 0.88 | 63 | 25.8 | 25.7 | | |
| | *GEV307_R0400_0035* | 181 | 3806 | 1.44 | | 27.2 | 27.2 | | |
| | *GEV307_R0400_0022* | 136 | 886884 | 2.57 | 62 | 26.7 | 26.7 | | |

*coupon tested at half of prescribed frequency

Figures 3-5 show an example of typical information which is available for each coupon. Fig. 3 shows the slow cycle measurements preceding the actual fatigue test. Closing of the upper grip

can be identified at the record where strain readings from the back-to-back sensors start to differ. After closing of the grips, the load was reset to zero. Figs 4 show the sections of the stress strain diagrams which were used for the establishment of tensile and compressive modulus (according to ISO [5]). Fig 5 depicts the ranges of the measurements which were taken at intervals during the test. In plots 3 and 5, all signals are normalised by their maximum. The numerical values of the maximum are plotted in the legend.

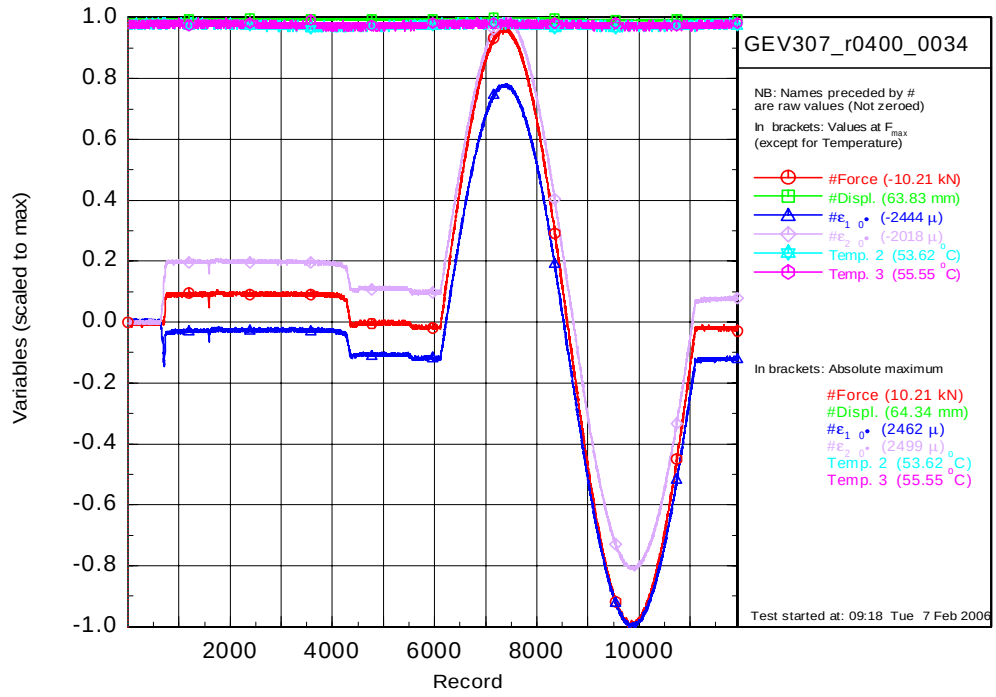


Figure 3: Slow cycle preceding fatigue test

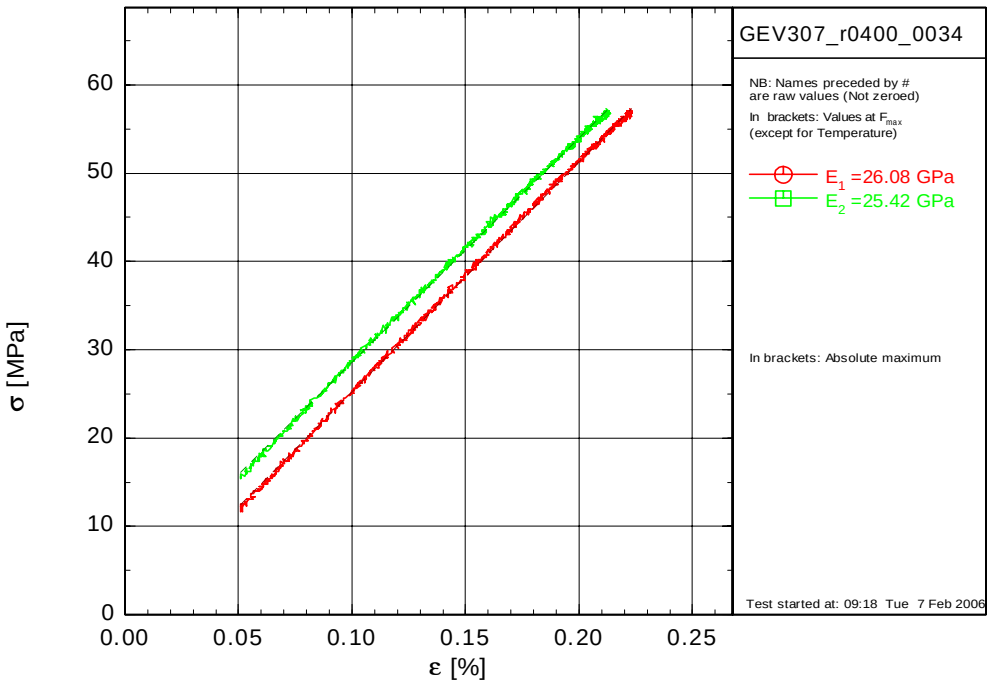


Figure 4: Part of stress-strain diagram used for modulus determination

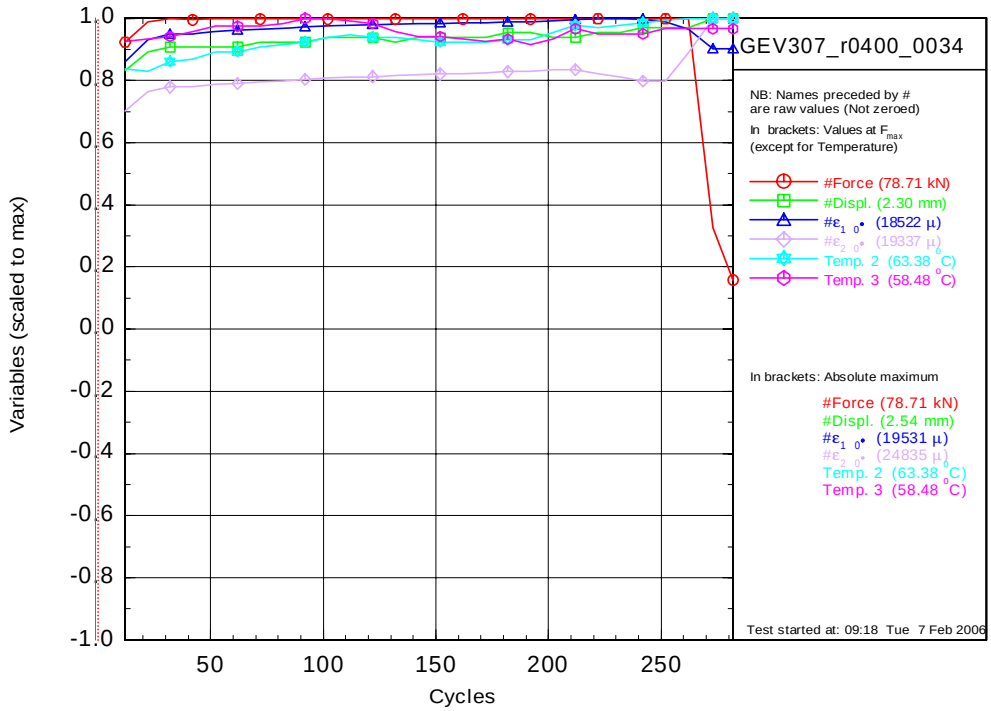


Figure 5: Normalised strain, load, displacement, temperature measurements at intervals during test

# Acknowledgments

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# References

1. Megnis, M., Brøndsted, P., 'Detailed Plan of Action for WP8 and WP9', OB_TG3_O001_005, doc. no. 10048_5, June 2004
2. Megnis, M., Brøndsted, P., Eriksen, K.P.,'Effects of extreme conditions on properties of the reference material', OB_TG3_R015_002, doc. no. 10167_2, September 2005
3. Smissaert, D.C.H., van Beek, C., 'Handleiding BFG', BFG versie 1.39, januari 2001 (in Dutch), WMC-group, 2001
4. Nijssen, R.P.L., 'OptiDAT – fatigue of wind turbine materials database', regularly updates via www.wmc.nl
5. ISO International Standard, 'Plastics - Determination of tensile properties - Part 1: General principles', ISO 527-1:1993(E), International Organization for Standardization, Genève, 1993