Figure 9: Composite specimens and test specimen

The fatigue testing was carried out with a stress ratio of R=0.1 and 4 load steps were conducted. A minimum of 3 specimens were used for each step. Figure 10 shows the SN curve of the high speed coupling composite as determined by fatigue testing.

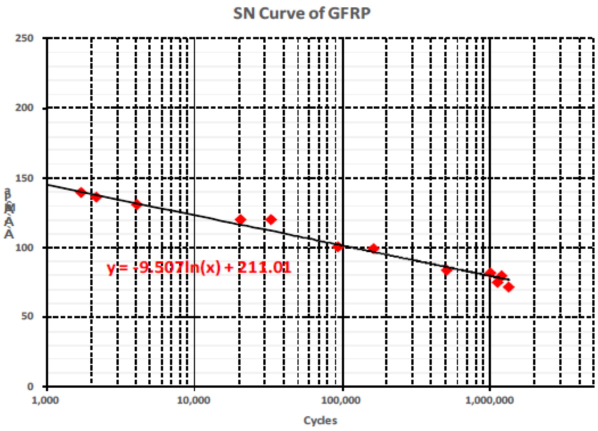

Figure 10: SN Curve of GFRP

Fracture strength testing is necessary for composite materials. This was performed using tensile testing. Tensile tests of 5 specimens were performed to obtain the average tensile strength of 248.5Mpa. The test results are shown in Table 7.

Table 7: GFRP tensile test results

No.	Width [mm]	Thickness [mm]	Area [mm2]	Force [N]	Strength [MPa]
1	23.82	3.50	83.37	20.85	250.1
2	23.66	3.37	79.73	19.83	248.7
3	23.81	3.37	80.24	19.94	248.5
4	23.82	3.25	77.42	19.17	247.6
5	23.65	3.28	77.57	19.21	247.7

The fatigue properties of the SCM440 material referenced in the literature, and its SN curve, are shown in Fig. 11. [13]

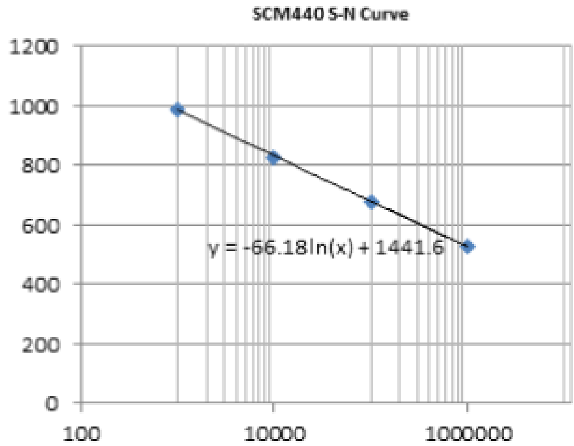

Figure 11: SN Curve of SCM440

HIGH SPEED COUPLING FATIGUE ANALYSIS

For the fatigue strength analysis, the Markov Matrix, which considers the torque and count applied to the high speed coupling and the maximum stress of each part when torque is applied, were calculated to determine the coupling's safety using the Accumulated Damage of the Palmgren Miner Rule. Figure 12 shows the Markov Matrix, which is the design load data for the 6MW wind turbine.

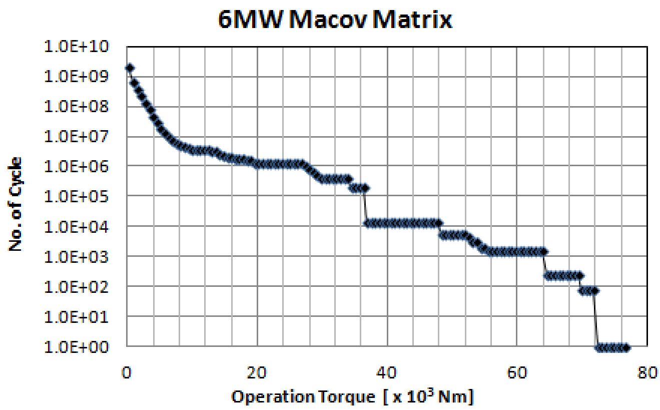

Figure 12: Markov Matrix curve of 6MW Turbine

The Accumulated Damage value was calculated using Eq. (1) which utilizes the Palmgren Miner Rule using the Markov Matrix, involving the load and cycle data.

$$D = \sum \frac{n_{Ei}}{N_{Ri}} \leq 1 \quad (1)$$

Here, n_{Ei} is the number of load cycles within the stress range of one category and N_{Ri} is the number of allowable load cycles within the stress range of one category.

Table 8 shows the Accumulated Damage values for the steel material Flange A and composite tube which were determined using the SN curves of Figs. 10 and 11 and Eq. (1). The Accumulated Damages were all below 1, verifying the safety of the parts.

Table 8: Accumulated Damage

Parts	Flange A	Composite Tube
Accumulated Damage	0.0483	0.9211

HIGH SPEED COUPLING TESTING

For the fabricated high speed coupling, damage was evaluated when the load condition of Case 3 was applied, and fatigue testing for the Markov Matrix was conducted. The damage for Flange A was set to be greater than 1 to minimize the number of test cycles. Table 9 shows the test conditions and the damage values for Flange A and the composite tube.

Table 9: Conditions and damage values for the accelerated fatigue testing

Torque [Nm]	Test Cycle	Flange A	Composite
57,000	1,000,000	0.49366	0.008484
65,000	10,000	0.29369	0.002588
120,000	400	0.26721	0.000176
Summary		1.0546	0.0112

The calculation results shown in Table 9 reveal that accelerated testing with heavy loads is possible for steel materials, but it can be observed that the accumulation of cycles dominates the fatigue life of composite materials, rather than the load magnitude. Figure 13 shows the accelerated test conditions for the high speed coupling.

Figure 13: 6MW High Speed Coupling Fatigue Test

CONCLUSION

Finite element analysis, fatigue analysis, and fatigue testing were carried out for each component to design a 6MW wind turbine high speed coupling, and the following conclusions were obtained in this study.

1) A maximum torque of 120,000 Nm, an axial misalignment of 10 mm and a radial misalignment of 25 mm were applied to the structural analysis of a 6MW wind turbine high speed coupling. Also, the combined load of the three load conditions was applied to assess the structural stability.

2) Structural analysis showed that the safety factor based on the yield strength compared to the maximum stress for all the major components including the brake disc, flange, spacer, torque limiter, and disc pack was 1.5 or greater. Thus, the safety of all the designs was verified.

3) The high speed coupling employs steel materials and composite materials for insulation. Since the composite material exhibits different properties depending on the winding angle, the SN curve was obtained through experimentation.

4) For the fatigue analysis, the Accumulated Damage value was determined through the Palmgren Miner Rule using the Markov Matrix, which includes the load and cycle data. Safety was verified, since the Accumulated Damage for all parts was less than 1.

5) Although accelerated testing with heavy loads is possible for steel materials, it was found that for composite materials, cycle accumulation dominated fatigue life, rather than the load magnitude.

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