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INFLUENCE OF OIL ON FILAMENT WOUND COMPOSITE MATERIAL USED IN AUTOMOTIVE GEARBOX

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Introduction

- Within a project TF03000050 funded by Technology agency of the Czech Republic, prototypes of two shafts with ring gears and a gearbox differential casing were manufactured by filament winding technology using carbon fiber reinforced polymer (CFRP) material.
- Not clear how the material reacts on the operating environment - oil
- Researches show negative effects of water and moisture on CFRP such as lower strength, stiffness and fatigue life, but mostly for composite laminates

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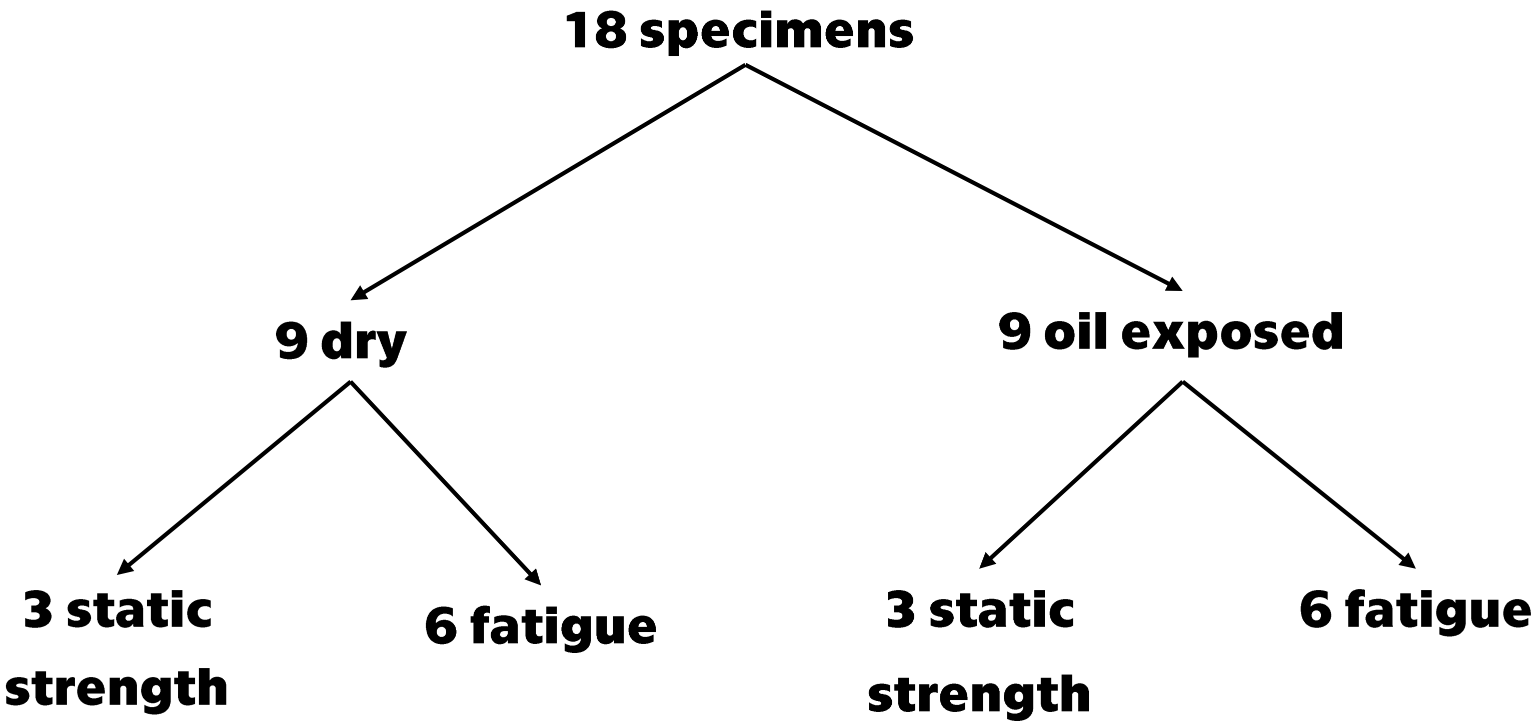
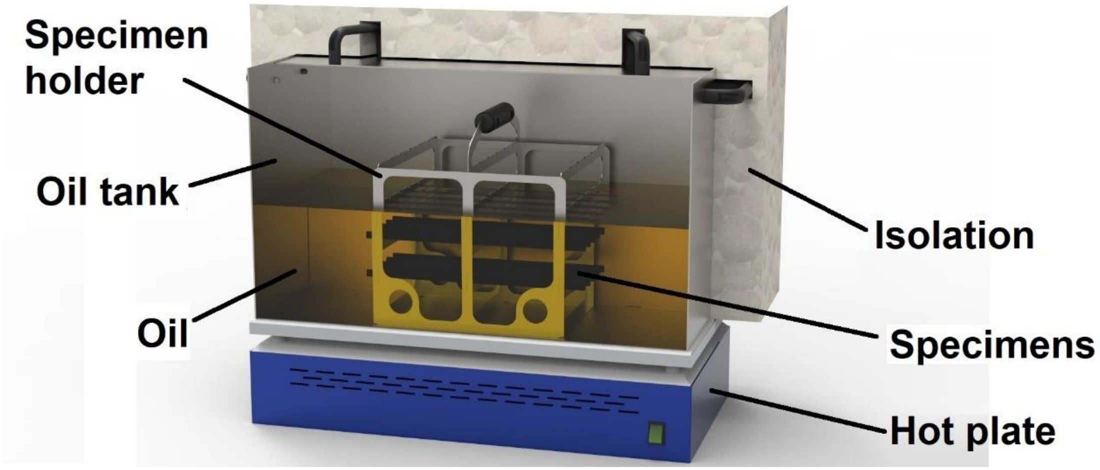
Experiments

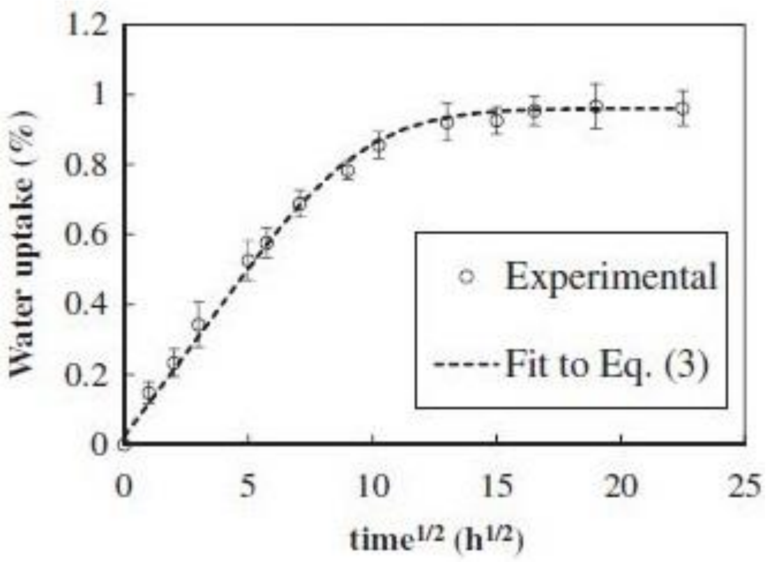
- Test specimens: tubes. Outer diameter- 15 mm, inner diameter- 9.9 mm, length- 310 mm



Exposure to oil

- Specimens were exposed to oil at 80 °C in an oil tank for approx. 2,5 months
- Mass progress was monitored
- Assumption based on researches studying the influence of water:
  - There will be a diffusion of oil into CFRP
  - The diffusion will follow Fick's second law of diffusion (see graph*)



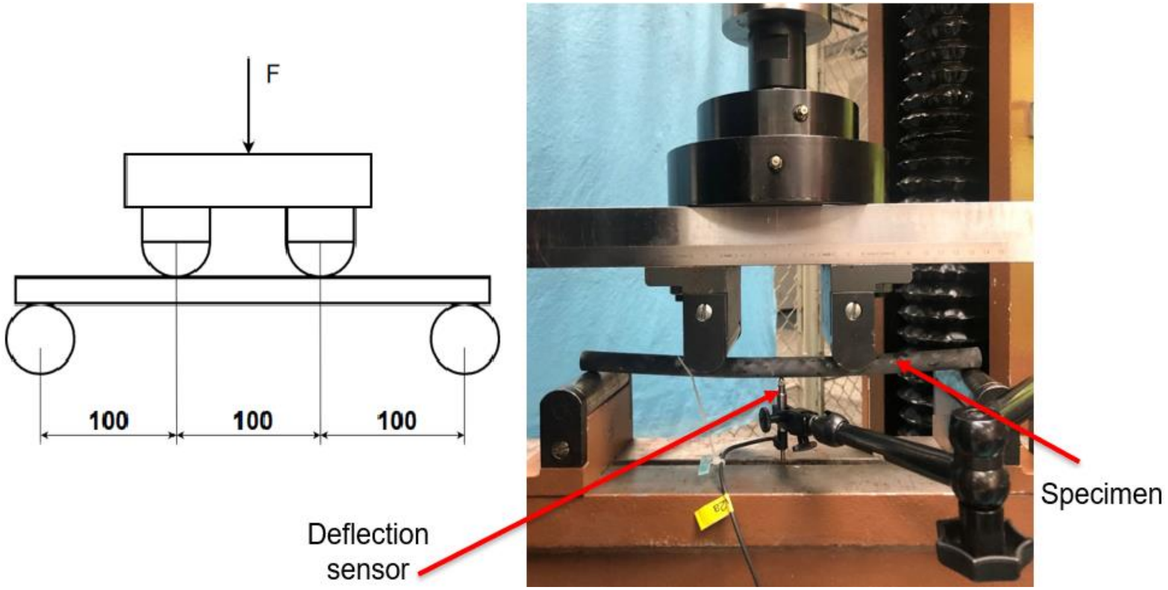


$$\frac{\partial C}{\partial t} = D_1 \frac{\partial^2 C}{\partial x_1^2} + D_2 \frac{\partial^2 C}{\partial x_2^2} + D_3 \frac{\partial^2 C}{\partial x_3^2}$$

*Gagani A, Fan Y, Muliana AH, Echtermeyer AT. Micromechanical modeling of anisotropic water diffusion in glass fiber epoxy reinforced composites. Journal of Composite Materials. 2018;52(17):2321-2335. doi:10.1177/0021998317744649

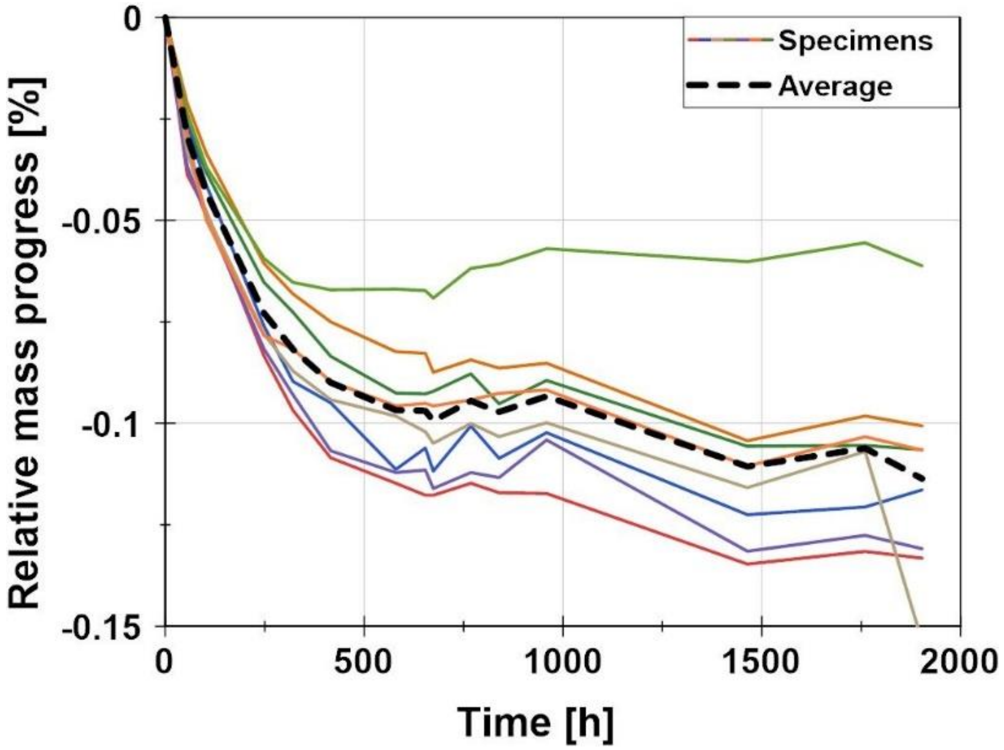
Mechanical tests

- 4-point bending setup for both static and fatigue tests
- Fatigue tests:
  - Frequency 10 Hz, R ratio 0.1
  - Load levels (F_{max}): 840 N, 900 N, 940 N, 980 N, 1100 N
  - Tests ran until 10^6 cycles were reached or until the specimen cracked
  - Degradation of stiffness was monitored
  - Specimens that reached 10^6 cycles were tested statically and residual strength was measured



Results – exposure to oil

- Contrary to the expectations, there was no mass increase, i.e. no diffusion of oil in CFRP observed.
- Minor mass loss was measured.
- Possible explanation: Oil reacted with surface of the specimens and eroded it. Worn away particles were removed by cloth during preparations for the measurements

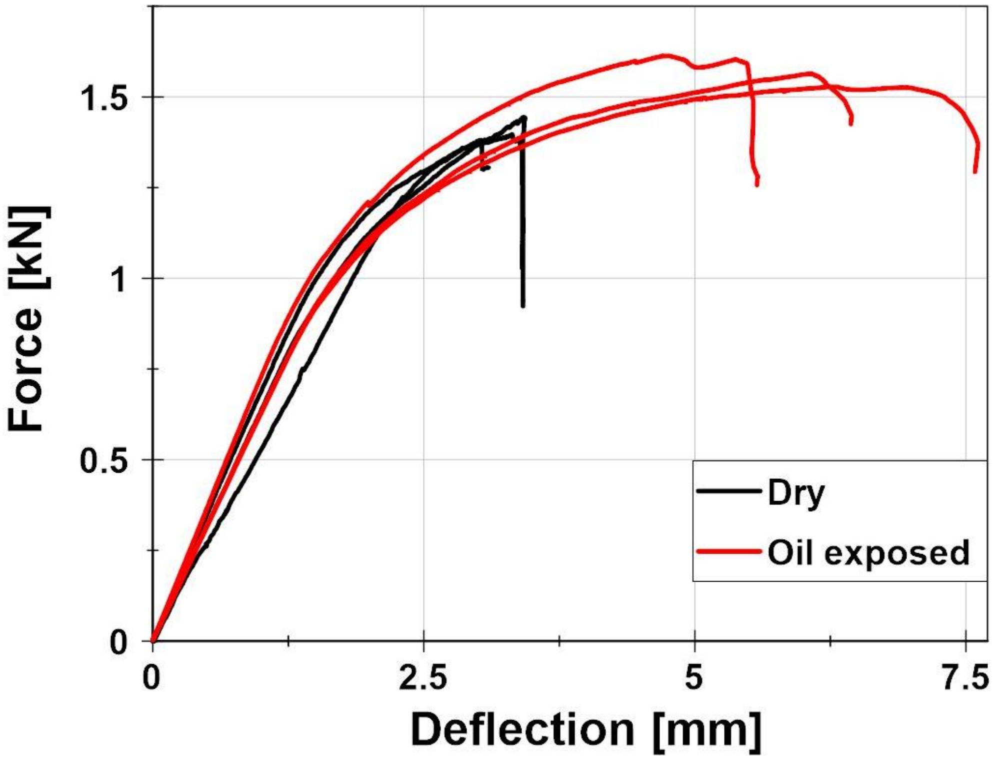


$$m_r = \frac{m - m_0}{m_0} \cdot 100\ [\%]$$

m_r – relative mass progress
m – current mass
m_0 – initial mass

Results: Static tests

- Flexural stiffness evaluated from the initial linear part of the curve
- No negative influence of oil on flexural strength or stiffness
- Oil exposed specimens have in average better results



Specimens	F_{max} [kN]	Stiffness [N/mm]
Dry	1.41	619.2
Oil exposed	1.57	648.6

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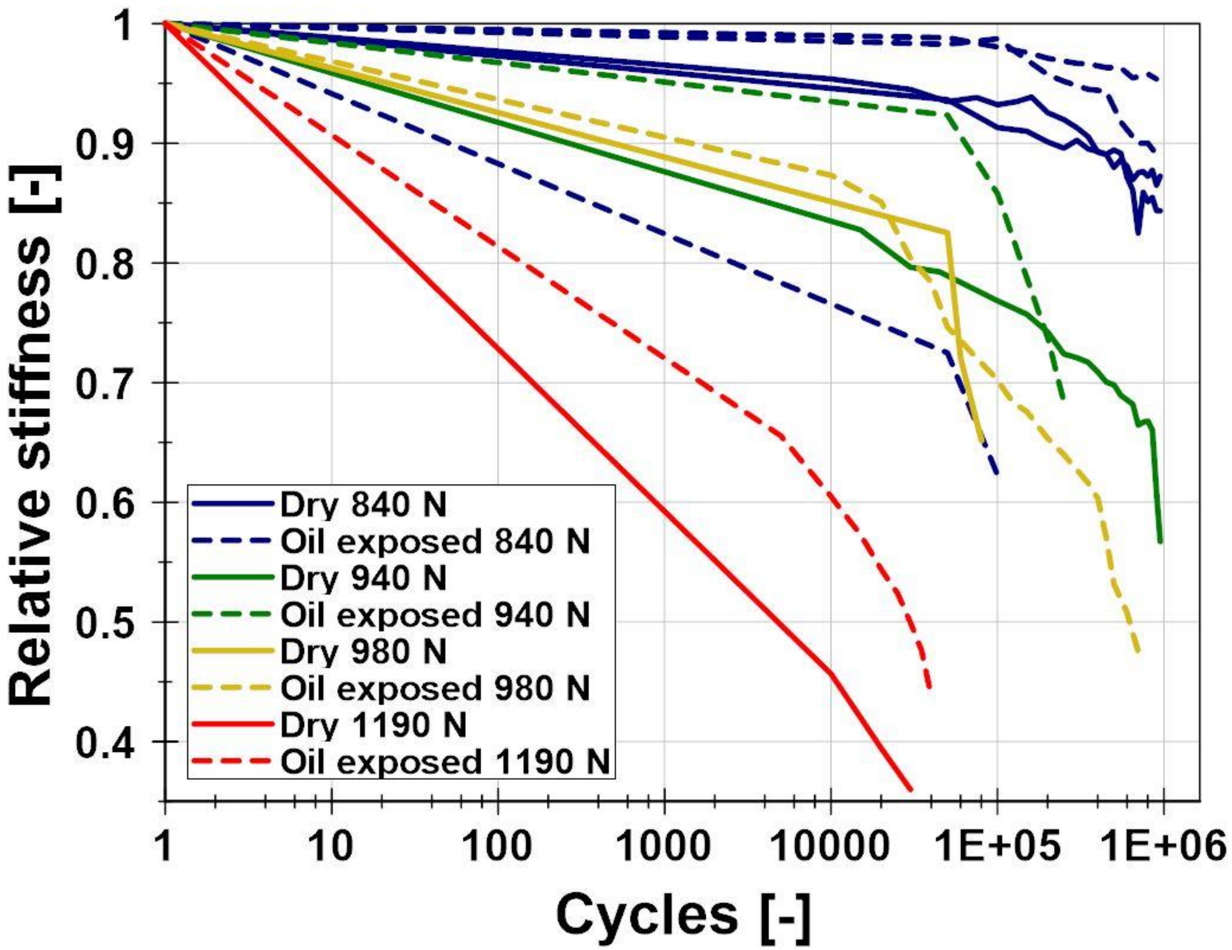
Tested specimens

Restults: fatigue – degradation of stiffness

- Flefural stiffness of oil exposed specimens (dashed lines) degrades slowlier in average than dry specimens (solid lines)

$$k_{rel} = \frac{k_n}{k_0}$$

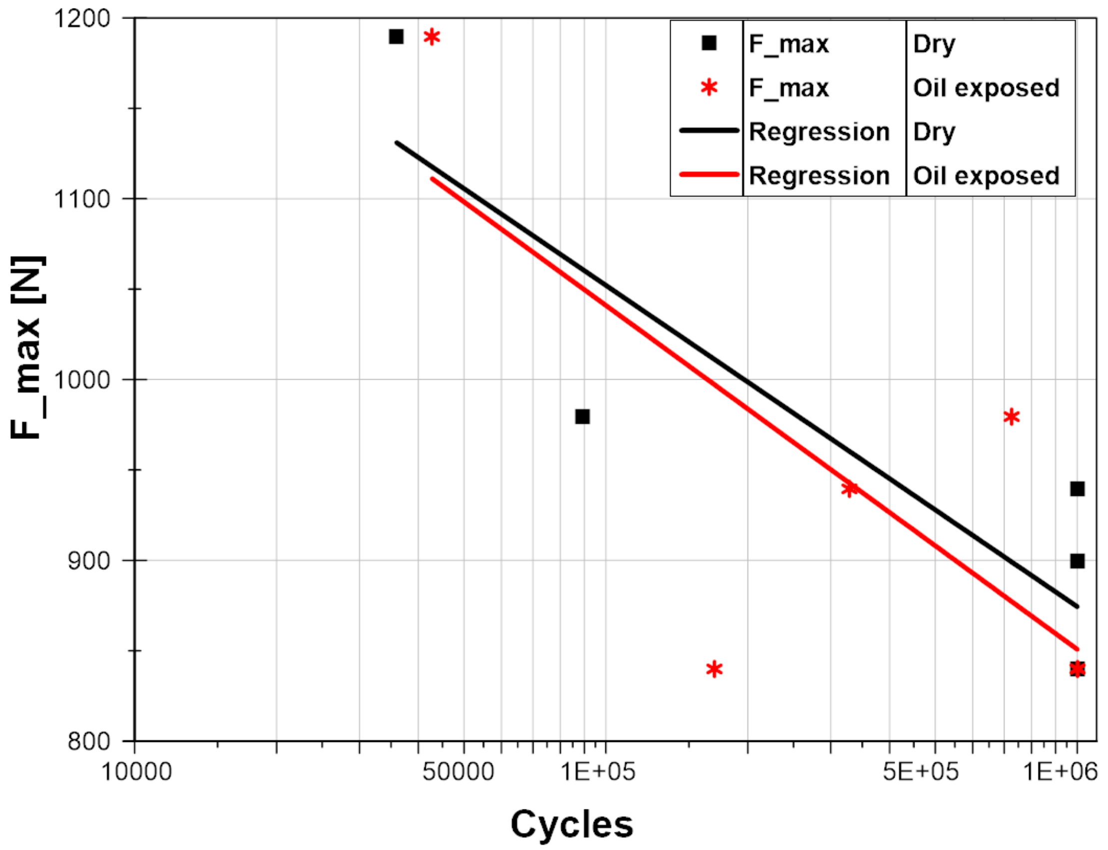
k_{rel} – relative flexural stiffness
k_n – flexural stiffness at n cycles
k_0 – initial flexural stiffness



Restults: fatigue life

- Only 2 oil exposed specimens ran up to 10^6 cycles in compare to 4 dry scpecimens
- Too little tests for results (and regressions) to be statistically relevant

F_{max} [N]	Dry	Oil exposed
	N [-]	
840	10^6 +	$2·10^5$
840	10^6 +	10^6 +
840	-	10^6 +
900	10^6 +	-
940	10^6 +	$3·10^5$
980	$9·10^4$	$7·10^5$
1190	$3·10^4$	$4·10^4$



Results: fatigue - residual strength

- If a level of 10^6 cycles was reached, specimens were statically tested for residual strength
- Although oil exposed specimens didn't reach 10^6 cycles at other levels of F_{max} than 840 N, residual strength at this level was higher, which corresponds with slower degradation of stiffness

F_{max} [N] (cyclic loading)	Dry	Oil exposed
	Residual strength [N]	
840	1580	1601
840	1599	1664
900	1580	-
940	1516	-

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Conclusion

- The material was expected to absorb oil during exposure to it at 80°C.
- Measurings showed no diffusion of oil, into CFRP, only a minor mass loss
- Mechanical properties of CFRP were expected to degrade after exposure to oil
- Against expectations, static tests proved stiffness and strength to be higher for oil exposed material
- Fatigue tests didn't show any negative effects of oil on mechanical properties as well
- Flexural stiffness of oil exposed specimens degraded slowlier during cyclical loading
- Fatigue life of dry specimens was slightly longer at lower load levels and shorter at higher load levels
- CFRP manufactured by filament winding technology have good performance under exposure to oil and have a perspective to be used in gearboxes