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

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Abstract: *Considering a possible use of carbon fiber reinforced polymers (CFRP) in automotive gearboxes, this paper investigates influence of oil on mechanical properties of CFRP. This particular research was a part of wide-focused project whose goal was to design a gearbox using large proportion of CFRP in order to reduce mass and noise. Part of this design was a filament wound shaft. In order to investigate an influence of oil on such part, 18 test specimens were manufactured. The specimens were simple tubes 15 x 9.9 x 300 mm with layup similar to the designed shaft. One half of the specimens was tested immediately and the other one after immersing in gearbox oil at elevated temperature of 80 °C for 83 days. Both test groups were then compared. The specimens were tested statically and dynamically in 4-point bending setup. Immersed specimens were regularly weighted, and mass progress was watched expecting diffusion behavior. The results have shown likely no negative effect of oil on CFRP and no oil diffusion in the material. Both flexural stiffness and maximal force increased and degradation of stiffness during cyclical loading decreased after oil exposure.*

Keywords: Filament winding, CFRP, Oil, Gearbox.

1. Introduction

There was a rapid development in use of composite materials in recent years. It allowed reducing mass and optimize designs in fields as aircraft, maritime or energy industries. Composite structures started to appear in automotive applications as well in context of constant pressure on reducing fuel consumption and lightweighting associated with it. As other materials, composites aren't inert to the environment they are operating in. Therefore, the effect of environment must be studied.

Previous researches examined influence of water and moisture on mechanical properties of composite materials. There has been observed negative influence on strength and stiffness (Kumar et al., 2002), fatigue (Khay et al., 2018) and decrease of glass transition temperature (Zafar et al., 2012). The decrease ranges from few percent up to 30 percent. Studies also showed that the changes in material properties aren't fully irreversible and can be partially or almost fully regained after removing from water and redrying. Authors of studies used various materials and technologies such as laminating (Kumar et al., 2008), injection molding short fiber composites (Mortazavian et al., 2015), filament winding (Almeida et al., 2016), all of them showed degradation behavior caused by water or moisture. Huo et al. (2018) investigated that the main cause of degradation is disrupting the interface between fibers and matrix. Some studies also focused on diffusion of water in composite materials. They observed that moisture uptake follows Fickian behavior (Huo et al., 2015).

Besides water and moisture, there's a research by Kim et al. (2017) that investigates influence of oil on carbon fiber reinforced polymers (CFRP). They used thin unidirectional laminates and also observed

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diffusion behavior (0.27 - 0.45 %) and decrease of tensile strength (0.72 - 2.21 %). This study investigates the phenomenon further on specimens manufactured by different technology (filament winding).

2. Experiments

There were 18 filament wound tubes manufactured that were used as test specimens. The tubes were 310 mm long with outer diameter 15 mm and inner diameter 9.9 mm. The specimens were split into two groups. One group to be tested without exposing to oil and the other one to be exposed to oil at elevated temperature of 80 °C for 83 days. The specimens were also weighted to record a progress of expected diffusion of oil. In each group there were three specimens tested statically by 4-point bending until they cracked.

The 4-point bending testing is shown in Fig. 1. The remaining six specimens were tested for fatigue up to 10^6 cycles with frequency of 10 Hz and load ratio R = 0.1 with 3 different amplitudes and then statically cracked if they remained undamaged. The configuration of 4-point bending for fatigue was the same as static test configuration. The results between exposed and unexposed specimens were compared.

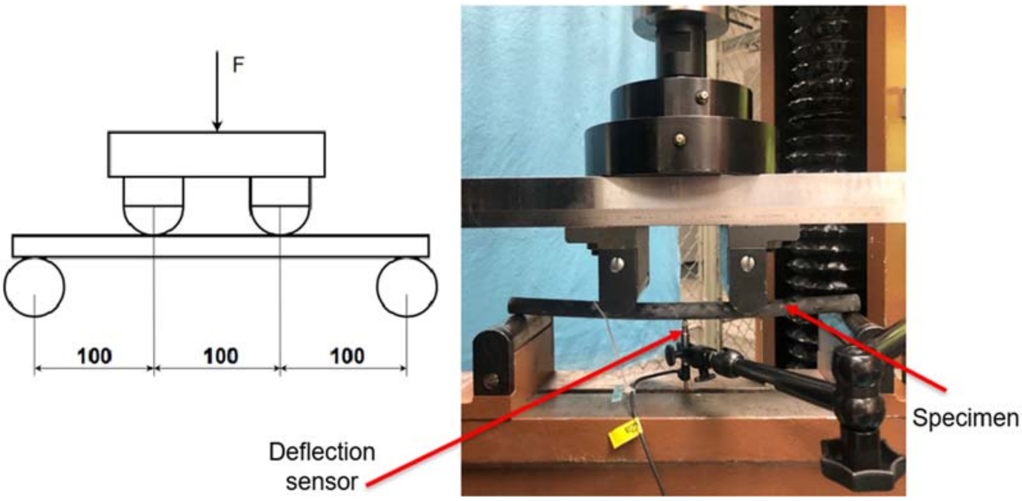

Fig. 1: 4-point bending setup.

3. Results

3.1. Mass progress of specimens exposed to oil

The original goal of this testing was also to analyze a diffusion behavior of oil in filament wound specimens. It means a saturation level and diffusion coefficient. The results in Fig. 2. are showing a different behavior than it was expected. Horizontal axis is time and vertical axis represents relative mass progress. The mass progress is relative to the first weighted value of mass after exposing to oil. The oil creates a film on the surface of the specimens so it would be misleading to relate the mass progress to weight before the exposure.

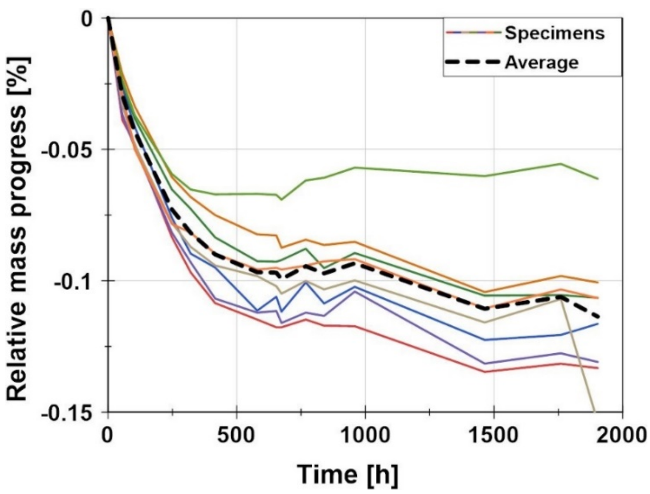

Fig. 2: Relative mass progress of specimens.

There wasn't any diffusion behavior observed, but there was relatively small mass loss. The main explanation of the mass loss is that the oil reacted with the surface of the specimens and caused a corrosion process. The corroded particles on the surface might have been removed by wiping by a cloth that was used to dry the specimens. There was no gasoline or other chemical used to remove the oil from the surface because it might also diffuse and chemically react with CFRP. We can conclude that there is negligible mass loss and probably no diffusion of oil into filament wound specimens.

3.2. 4-point bending static tests

There were two important parameters measured in the test. The first is F_{max} which is the maximal force when a rupture occurred. The other one is flexural stiffness of the specimen. The stiffness was evaluated from the first, linear part of the deflection-force curve. The results of 4-point bending static tests can be seen in Fig. 3 and Tab. 1. It appears that exposing the filament wound shafts to oil and high temperature didn't have any negative impact on mechanical properties.

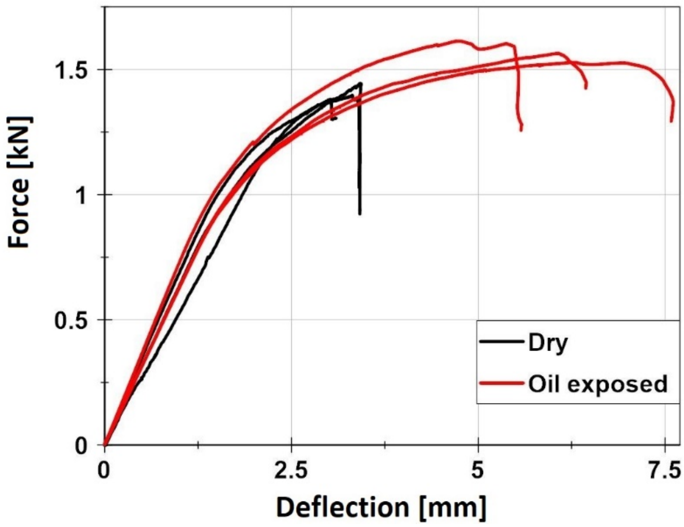

Fig. 3: Static 4-point bending test.

Tab. 1: Static 4-point bending test. Average values.

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

3.3. 4-point bending fatigue tests

The main focus during fatigue tests was on a degradation of stiffness depending on the maximal force (F_{max}) and number of cycles. Values of F_{max} were 840 N, 940 N, 980 N and 1190 N. The results are shown in Fig. 4 and Tab. 2. The specimens that passed 10^6 cycles were then statically tested for residual strength F_{res}.

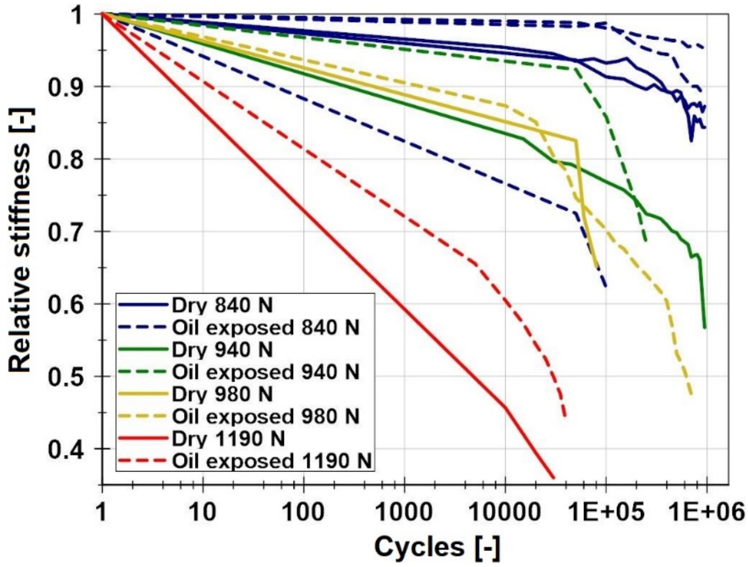

Fig. 4: Degradation of stiffness during 4-point bending fatigue tests.

Tab. 2: 4-point bending fatigue test results.

State	Dry						Oil exposed					
F_{max}[N]	1190	980	940	900	840	840	1190	980	940	840	840	840
F_{res} [N]	-	-	1516	1580	1599	1580	-	-	-	1664	1601	-
N [-]	$3 \cdot 10^4$	$9 \cdot 10^4$	10^6	10^6	10^6	10^6	$4 \cdot 10^4$	$7 \cdot 10^5$	$3 \cdot 10^5$	10^6	10^6	$2 \cdot 10^5$

The degradation of stiffness relative to the stiffness before cyclical load is shown in Fig. 4 where solid curves relate to dry specimens and dashed lines relate to oil exposed specimens. Load levels are differentiated by colors. We can see that oil exposed specimens are degrading slower than dry specimens at the same load level even though the life is usually shorter or the same.

4. Conclusions

There were 18 filament wound specimens tested in this study. Half of them were exposed to oil at 80 °C. Static and fatigue tests were done in configuration of 4-point bending and both groups were compared. The results showed that the behavior of oil exposed specimens didn't meet expectations. There was a mass loss observed during exposure. Also, maximal force during 4-point bending static tests was higher at oil exposed specimens, and flexural stiffness didn't decrease as well. It can be concluded that oil at high temperature has most likely no negative impact on static mechanical properties CFRP filament wound shafts. Oil exposed specimens tended to crack earlier during fatigue tests. On the other hand, relative degradation of stiffness was slower for oil exposed specimens at the same load level in compare to dry specimens.

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