8 Abstract

Materials used in fuel system design, most of which were selected more than 30 years ago, successfully met the standards of their time and exhibited high durability. However, current requirements related to CO_2 emission reduction and the introduction of new biofuel components are changing the operating conditions of fuel systems, including increased fuel temperature and pressure, higher dynamic loads, and the presence of chemically aggressive components. One of the elements requiring verification under these conditions is the form-fit connection between the fuel pump turbine and the drive shaft. The present work focuses on the analysis of damage mechanisms in the D-drive form-fit connection transmitting torque from a steel shaft to the hub of an internal combustion engine fuel pump turbine made of short glass-fiber-reinforced polyphenylene sulfide (PPS/GF), and subsequently on the assessment of the applicability of polyoxymethylene (POM) composites containing 7% and 15% short basalt fibers (POM/BF) as alternative materials.

The PPS/GF investigations were carried out using accelerated service tests of complete fuel pumps, reproducing start-up cycles and operation in the presence of a hot alcohol-containing fuel mixture (FAM B). The identification of degradation mechanisms was based on microscopic analysis, FTIR, DSC, XRD, and finite element modeling. In the case of PPS/GF, no significant changes in the degree of crystallinity after aging under the adopted conditions were found in material taken from regions remote from the contact zone. At the same time, local structural changes detected in the turbine hub region, combined with the results of finite element calculations, indicate that the main degradation mechanism was cyclic contact stress leading to fatigue damage after a stage of controlled wear, rather than the effect of the fuel environment alone. The crystallinity changes identified in the load-transmitting region were local in character and were associated with a damaged zone showing features of fatigue failure, whereas in material taken from regions remote from the hub the influence of aging was weak and barely detectable.

In the initial state, the POM/BF composites exhibited clearly better strength properties than unreinforced POM, together with positive dimensional strain resulting from processing-induced expansion. After aging in the FAM B mixture, their tensile strength decreased to the level of POM, while elongation at break and energy absorption increased, especially in the case of the B7 composite. Under bending conditions, the aged composites still outperformed POM in terms of strength and elastic modulus. Aging reduced the tribological wear resistance of all investigated materials under high contact pressures. The highest resistance was shown by POM, whereas the B7 composite retained application potential due to its favorable compromise between mechanical properties and wear performance.

FTIR analysis did not reveal any new bands characteristic of advanced chemical degradation of POM. The observed changes were subtle and were limited mainly to the near-surface layer of the material. Due to the overlap between bands characteristic of the POM matrix and possible bands associated with basalt fibers, this method did not allow unambiguous identification of either the contribution or the degradation of the fibers. DSC analysis revealed changes in melting temperature and enthalpy, indicating reorganization of the crystalline structure of the materials during aging and tribological operation. Complementary XRD analysis indicated changes in the crystalline structure of the matrix in the near-surface layer, with these changes being more pronounced in POM than in the composites. Based on the combined SEM, FTIR, DSC, and XRD analyses, it was concluded that the degradation of POM/BF composites is multi-mechanistic in nature; however, the decisive factor in the deterioration of their mechanical properties is the degradation of the fiber–matrix interphase, whereas structural changes in the matrix itself are secondary. This process is manifested by weakened adhesion and damage to the fiber surfaces, leading to a deterioration in load-transfer efficiency.

The study demonstrated that, under the new operating conditions of PPS/GF in a fuel pump turbine working in a hot alcohol-containing fuel mixture (FAM B), the decisive contribution to the destruction process came from local cyclic contact stresses rather than from the fuel environment alone. This conclusion was based on the absence of significant changes in the degree of crystallinity in material remote from the contact zone after aging, together with the identification of local crystallinity changes in the turbine hub region, consistent with the areas of elevated stress revealed by the numerical model and with the locations of cracks and fatigue damage developing after the stage of controlled wear. A second scientific achievement of the work was the investigation of the effect of aging of POM/basalt fiber composites in a hot alcohol-containing fuel mixture (FAM B) on their mechanical properties and wear characteristics. The implementation-oriented objective achieved in the study was the acquisition of data useful for the design of components and materials operating in fuel systems under new service conditions, in which the POM composite containing 7% basalt fiber showed implementation potential under new optimization criteria taking into account carbon footprint and the predictable loss of mechanical properties.