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Nylon degradation with automatic transmission fluid

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Abstract

Nylon is used as a material in the design of various components of automatic transmissions, namely pump rotor guides and thrust washers. These nylon components must be compatible with automatic transmission fluid (ATF). Field and laboratory cycling testing of experimental ATFs showed that nylon components in contact with ATF underwent color changes and exhibited loss of tensile strength. A laboratory bench test was developed to simulate these occurrences. The end-of-test nylon 6 and nylon 6/6 test pieces, the cycling test pieces, and the field parts were analyzed. Differential scanning calorimetry (DSC) and X-ray diffraction (XRD) data show that the crystallinity of the nylon materials increased, probably from decomposition of plasticizer, and the increasing crystallinity is responsible for the loss of tensile strength. With the field test pieces, degradation of the actual nylon component followed the plasticizer decomposition. Nylon test pieces placed in an oven showed the same changes in color and tensile strength as the field pieces and bench test pieces. From this, it was concluded that the nylon changes were not due to chemical interactions with ATF, but rather from heat. The ATF actually reduced the thermal effects on the nylon. This paper outlines the thermal and X-ray analyses of the nylon test pieces to illustrate the interaction of nylon 6 and nylon 6/6 with automatic transmission fluids. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Automatic transmission fluid; Differential scanning calorimetry; X-ray diffraction; Nylon

1. Background

Nylon is primarily used in automatic transmissions as thrust washers, wiring harness clips, and pump rotor guides. When formulating automatic transmission fluid, it is important to understand the compatibility of ATF formulations with the nylon components. An immersion test was developed to investigate the ATF–nylon interaction. Nylon 6/6 thrust washers and vane pump rotor guides from both field taxi cab transmissions and transmission cycling tests were also studied.

Since darkening of the nylon parts occurred with field testing, the immersion bench test was developed to simulate the color change. The major concern was whether or not the color changes were indicative of loss of component strength. In the bench test, nylon 6 and 6/6 test pieces were immersed in various mineral and synthetic base oils and ATF formulations for specified periods of time [1]. Effects of air, air delivery methods, temperature, and time were investigated. To understand the changes due solely to ATF, samples were suspended in an oven without fluid and then compared to the bench test samples. Nylon degradation was measured by changes in color, tensile strength, differential scanning calorimetry (DSC) and X-ray diffraction (XRD).

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Results from the bench test showed that with increased time and/or temperature, the samples became brittle and darkened in color. The color change occurred whether or not air was present, but air did catalyze the reaction. Samples suspended in the oven showed more severe color and tensile changes than the samples tested in ATF. Thus, the ATF protected the nylon 6 and nylon 6/6 from thermal degradation effects. Loss of tensile strength occurred over the total test time, but color and tensile strength were not necessarily interdependent. Although the bench test simulated the physical changes of the nylon 6 and nylon 6/6 samples, further work was necessary to understand the cause of the changes. The DSC and XRD data illustrated the two-phase degradation mechanism. The elastomeric portion degrades first followed by the crystalline nylon.

2. Experimental procedure

The immersion bench test is described in detail elsewhere [1], and only a summary will be discussed here. The immersion test used precut nylon pieces suspended in a test tube filled with experimental fluid. The test tubes were placed in a heated oil bath for specified periods of time. Variables were air flow, air delivery method, temperature, and time. Test temperatures were 150, 163, and 200°C. Most time studies were performed at 163°C to 300 h, and only that data will be discussed here. In some cases, 100 h was the maximum time until the oil sample started to solidify.

Nylon parts from both field and laboratory cycling test transmissions were studied for comparison to the immersion bench test specimens. Nylon thrust washers and pump rotor guides were supplied from taxicab fleets employing hydraulically operated GM 4L60 transmissions [1]. The bench cycling tests were performed in accordance with the DEXRON®-III Automatic Transmission Specification using friction material specified for prototype DEXRON®-IV development [2,3]. This prototype development testing has been described elsewhere [3,4].

Several techniques were used to analyze the nylon samples. First, a color rating scale was developed to characterize the visual appearance of the nylon [1], but only the degree of color change will be summarized here. Second, the nylon was tested to identify changes in the material integrity. To compare the relative strength of the new and end-of-test (EOT) nylon pieces, the tensile force was measured using a Tinius–Olson testing machine. Each piece was pulled at 0.10 mm/min, and the tensile force required to break the test piece was recorded. The relative crystalline properties of the nylon pieces were measured by DSC and XRD. A TA Instruments differential scanning calorimeter (DSC 910) with cooling capability was used. Temperature was ramped at 5°C/min from 30 to 350°C. The heat of the endothermic crystalline melt was measured for each sample. X-ray diffraction data were obtained using a Philips X-Pert XRD system. Each sample was scanned for $10<2\theta<60^\circ$ using Cu$K\alpha$ radiation at a continuous scan rate of 0.5°/min.

3. Results and discussion

Initial tensile measurements of the nylon 6 and nylon 6/6 test pieces from the immersion bench test showed a loss of tensile strength throughout the test time. On average, the nylon pieces lost over 80% of the original tensile strength (Fig. 1). These same test pieces also became darker in color throughout the test: the color turned from a white or whitish-yellow to orange then purple and finally black or dark brown [1]. The tensile strength data illustrates the catalyst effects of air for both nylon 6 and nylon 6/6. DSC and XRD analyses were performed on the EOT samples, and it became evident that the crystalline character of the nylon samples increased throughout the test. The plasticizer degrades to yield higher crystalline character in the sample followed by degradation of the crystalline nylon species.

Fig. 1 shows the change in tensile strength for nylon 6/6 tested with and without air delivery in the same ATF formulation. Nylon 6 follows a similar trend (Fig. 2). By 300 h both samples show loss of 80% tensile strength. However, the sample with air bubbling through the fluid shows the major tensile loss between 32 and 100 h. The sample with no air bubbled through the fluid does not show major loss in tensile strength until after 100 h. Clearly, the loss in tensile strength is due to thermal effects, but the mechanism is catalyzed by oxidation.

DSC analysis of the nylon pieces from the immersion bench test showed that the endothermic heat of

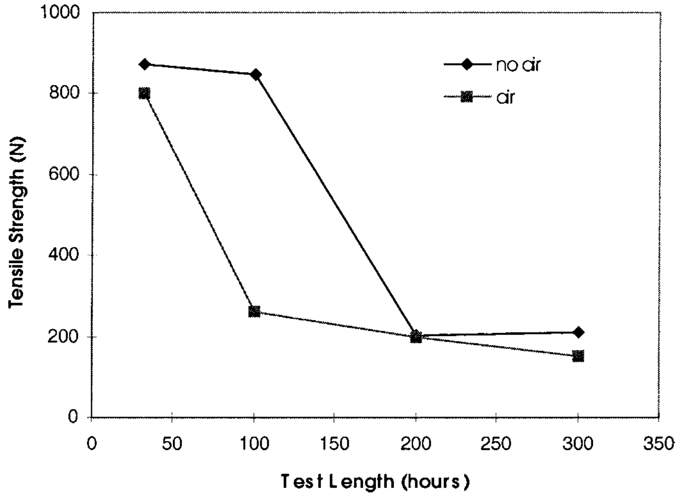

Fig. 1. Tensile strength of nylon 6/6.

melt for the EOT pieces was higher than those values for the nylon pieces at 32 h into immersion. Fig. 3 compares nylon 6/6 heat of melt for immersion test pieces with and without air bubbled through the fluid. Here, there is no statistical significance between air delivery; however, heat of melt did statistically show a significant increase from 32 to 300 h of immersion testing. On average, the nylon 6/6 samples increased from 60 to 75 J/g (Fig. 3), while nylon 6 increased from 68 to 78 J/g.

The increasing endothermic heat is evidently due to increasing crystallinity of the nylon 6/6 and nylon 6 samples. The elastomeric portion of the nylon degrades due to thermal effects and results in increased crystallinity of the remaining material. This phenomenon is supported by the decreasing tensile strength. As crystallinity increases in a material, the more brittle the material becomes.

The role of the ATF is not only to provide lubrication and heat transfer for the transmission, but also to provide protection to transmission components against thermal and oxidation stresses. In order to understand whether or not ATF was providing such protection to the nylon, testing was also performed

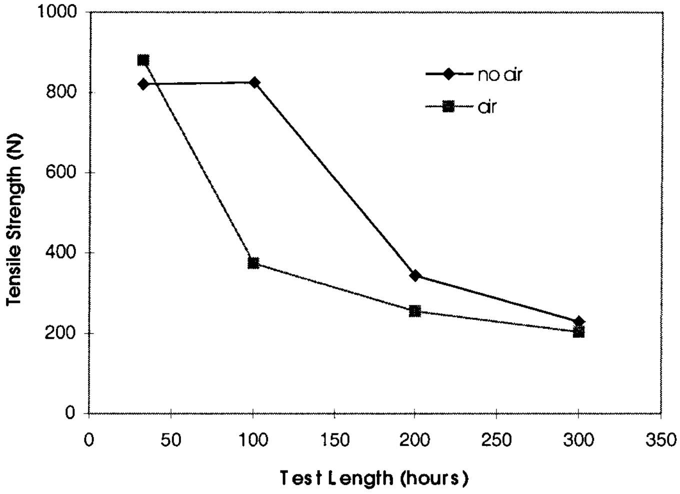

Fig. 2. Change in tensile strength for nylon 6.

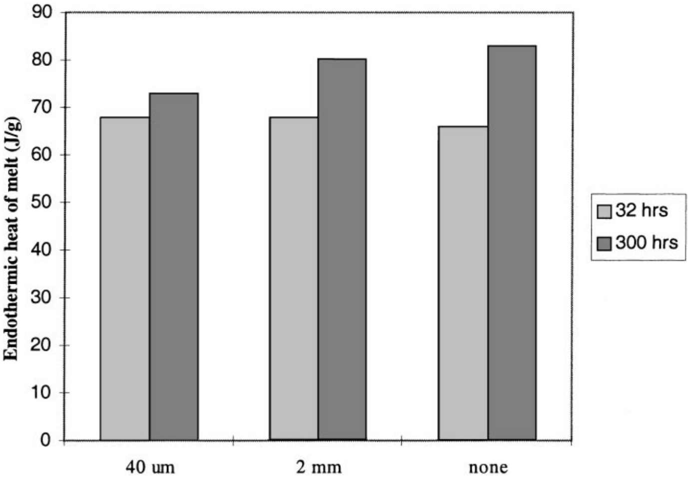

Fig. 3. Increasing crystallinity of nylon 6/6 through 300 h of immersion testing.

with a nylon piece suspended in a 163°C oven, an ATF formulation, and an unadditized base oil (Fig. 4). The nylon tested in ATE showed the lowest change in crystallinity as compared to the oven testing or immersion in base oil. Clearly, the ATE additives provide protection from both heat and base oil effects.

The DSC curves for the field samples (Fig. 5) show that a high degree of degradation occurred in the thrust washers and pump rotor guides. The DSC curve of the EOT thrust washer shows two distinct melt phases with onset temperatures ca. 235 and 275°C. The 235°C is the typical nylon 6/6 melt while the 275°C melt is an unknown species, probably nylon degradation products. The DSC curve for the EOT pump rotor guide illustrates that little of the sample is nylon 6/6, while most of the remaining material is the nylon degradation product. X-ray diffraction data shows a similar transition (Fig. 6). The diffraction pattern for the new pump rotor guide shows two broad peaks (20.5 and 23.5° 2θ), Fig. 3: indicative of semi-crystal-

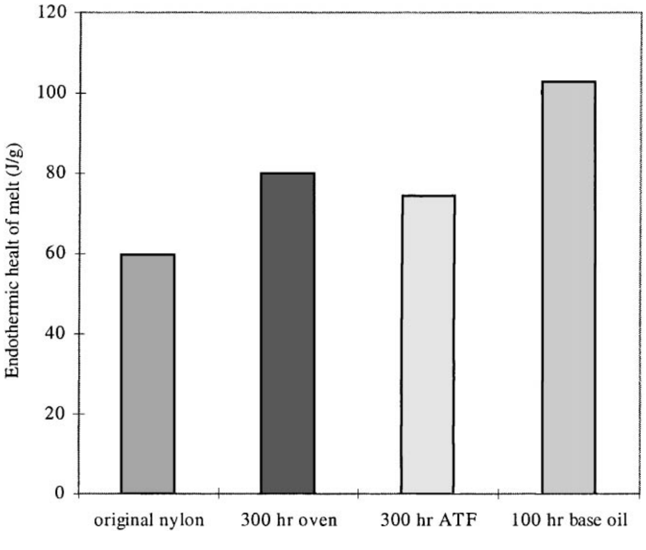

Fig. 4. ATF additives protect nylon from heat and base oil.

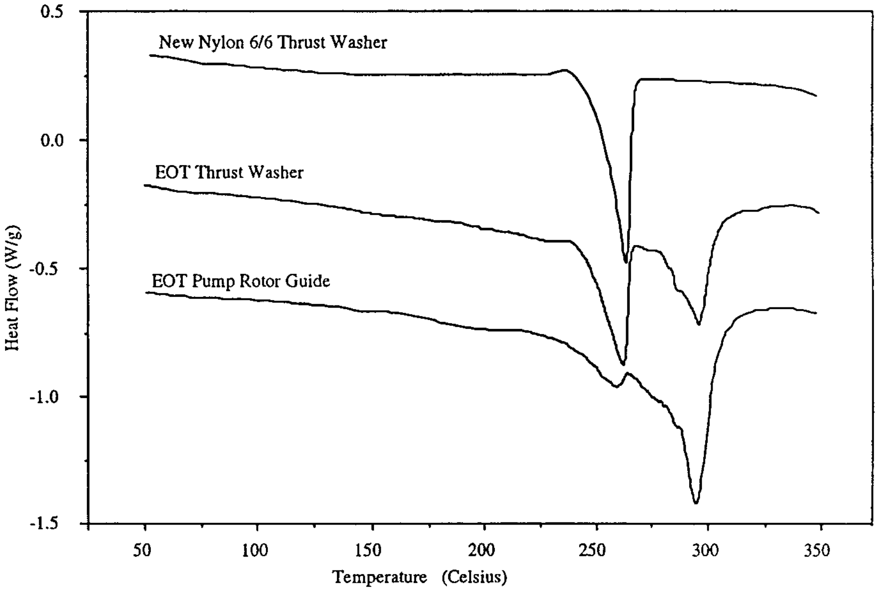

Fig. 5. DSC data for new and EOT field parts (offset for comparison).

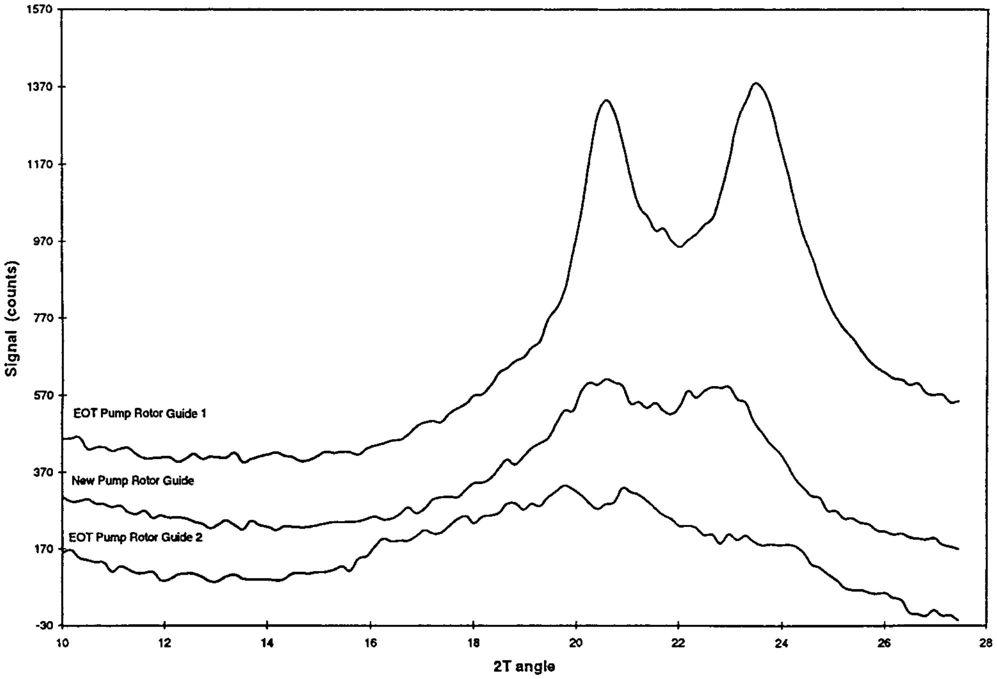

Fig. 6. XRD data for new and EOT field parts (offset for comparison).

line materials. The XRD pattern for a used pump rotor guide shows the transition to more clearly defined peaks with increased crystallinity in the material. Finally, a failed field sample is shown to be almost totally amorphous (XRD, Fig. 6) with minimal crystalline nylon (DSC, Fig. 5).

By comparing the bench test data with the field test samples, the mechanism of nylon degradation with ATF is pieced together. It appears that, initially, the elastomer component of the nylon 6/6 pieces starts to degrade, yielding higher crystallinity in the samples with loss of tensile strength and color change, illustrated by the bench test samples. As degradation progresses, the nylon component starts to degrade, as shown with the field samples. By this time, there is complete loss of tensile strength and the nylon components appear black in color.

4. Conclusions

Physical changes in nylon 6 and nylon 6/6 observed in laboratory and field tests are not heightened by automatic transmission fluid. Color change and loss of tensile strength are probably due to thermal effects, and the ATF additives most likely serve to protect the nylon surface from heat and base oil. The thermal degradation is observed as a two step process: the plasticizer moiety degrades first, followed by the bulk nylon entity. The laboratory immersion bench test does simulate the plasticizer degradation step, but it is not severe enough to actually degrade the nylon as seen in the fleet and laboratory cycling tests. In order to simulate bulk nylon degradation, further work would be necessary.

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