

CREEP AND FATIGUE OF LONG GLASS REINFORCED POLYPROPYLENE COMPOUNDS

**Charles C. Mentzer
Peter H. Foss
General Motors**

Abstract

This paper details the creep and fatigue characteristics of several long glass reinforced polypropylene compounds that have been used in the development of a thermoplastic liftgate. Both the creep and fatigue data show stress levels associated with a composite part should be limited to 30 % of the failure strength at the maximum use temperature. Parts where there is considerable flow and orientation of these composites should limit stress levels in the cross-flow direction to less than 20 % of the failure strength in that direction.

Introduction

Polypropylene reinforced with various types of long glass fibers have been used in several automotive applications especially in Europe [1]. A paper [2] presented at the 2004 SPE Automotive Composites Conference documented the development of a liftgate fabricated using long glass fiber reinforced Polypropylene (PP). In normal use the liftgate subjects these PP compounds to both creep and fatigue. The gas struts for the liftgate and glass introduce a constant load which could lead to localized creep at the attachment points. Vibrations during operation and opening and closing of the liftgate could lead to fatigue failure. Creep and fatigue of long glass reinforced PP were investigated to determine what stress would lead to creep rupture and fatigue failure. Fatigue of injection molded glass reinforced thermoplastics has been investigated by many researchers [3, 4]. Their results indicate fatigue data could be normalized by the initial modulus of the test specimen [4]. The current fatigue experiments were undertaken to determine if the data could be normalized by the failure stress obtained from a standard tensile test. These long glass reinforced PP compounds have much lower elongation at break than the injection molded resins. (1 to 1.5% versus 2 to 3%) which means the initial modulus and overall modulus based on the failure stress are similar.

Molding

Four long glass reinforced polypropylene (PP) materials were used in the creep and fatigue experiments. Two GMT Azdel products R401 and C467 were used as standard materials. R401 consists of PP containing 40% by weight random continuous glass fibers. C467 consists of PP containing 35% by weight 12.5 mm random chopped fibers and 10 % by weight talc. These two materials were molded into 22 by 29 cm plaques. To minimize flow orientation during molding, the plaques were molded using an 80 % initial charge (20 by 28 cm). Two configurations of tensile bars routered from these plaques, one with a 12.5 mm reduced section and another with a 38 mm reduced section.

The creep experiments also were conducted using a PP compound containing 40 % by weight random chopped 25 mm glass fibers. Tensile bars (12.5 mm) were routed from 45 by 60 cm plaques molded at Composite Technologies, Corp. (CTC) in Dayton, OH. The plaque configuration and charge placement are shown in Figure 1.

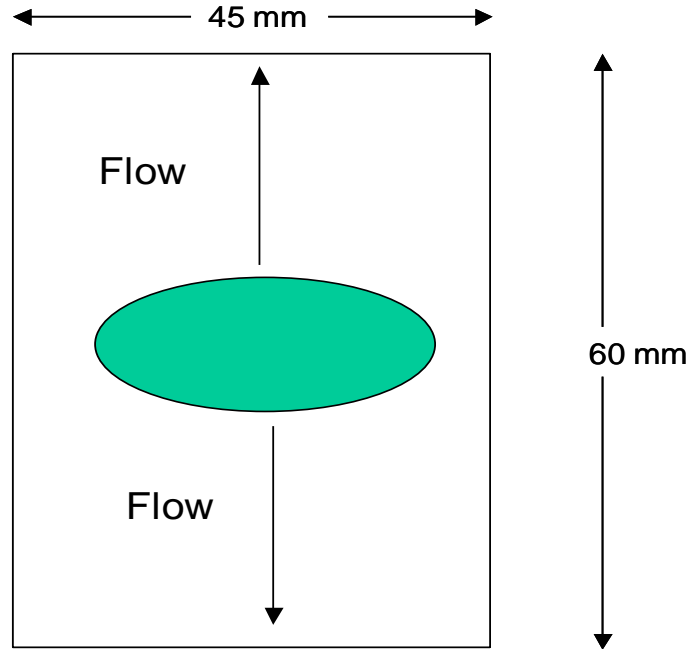


Figure 1. CTC liftgate material plaques showing charge placement and flow direction.

This charge placement resulted in orientation in the 60 cm direction. Tensile bars were cut parallel and perpendicular to flow. The liftgate material used in the fatigue experiments was molded at Composite Product Inc. (CPI) in Winona, WI using 40 % by weight 12.5 mm glass fibers. The tensile bars were cut from the window portion of the outer upper panel of the 360 liftgate (Figure 2). Figure 3 shows how the 38 mm tensile bars were routed from the window section.

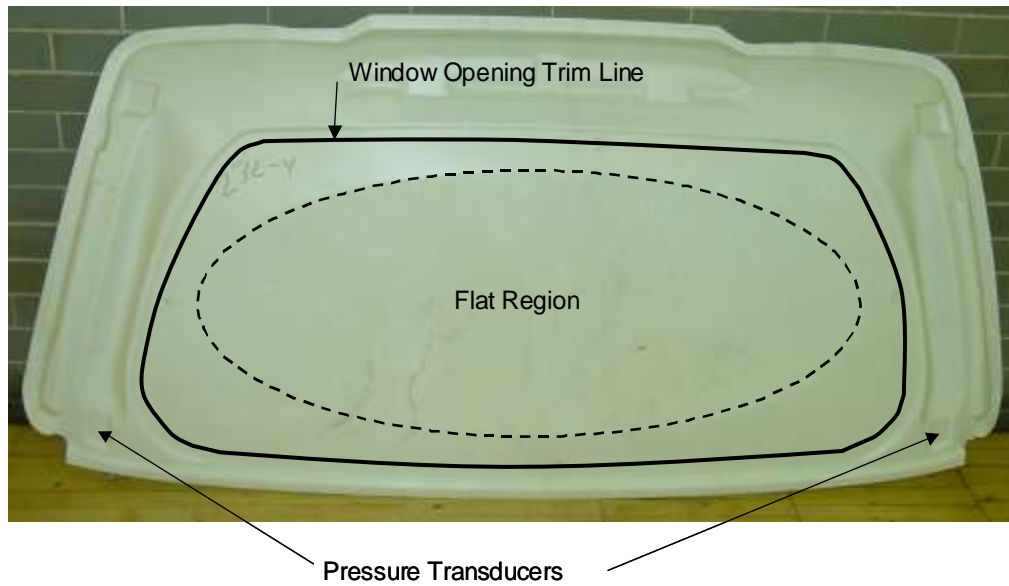


Figure 2. Upper outer liftgate panel showing region used for tensile bars.

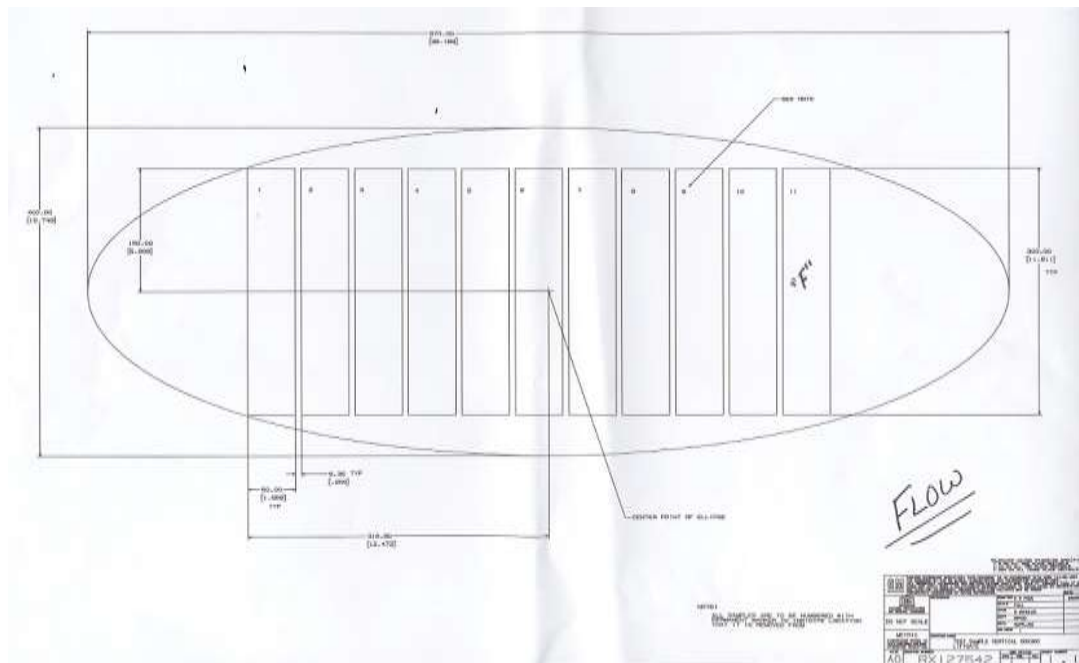


Figure 3. Tensile bar layout for 38 mm CPI liftgate material.

Results

Tensile data for the four materials is shown in Table 1. Only the GMT R401 tensile properties were measured at 80°C. Five samples were used for each tensile test. Creep and fatigue stress levels were set based on the tensile strength for each material.

Table I

Tensile Properties of Glass Filled Polypropylene used in Creep and Fatigue

Material	Tensile Strength, Mpa	Standard Deviation
GMT R401, 23°C	124	7.8
GMT R401, 80°C	100	9.1
GMT C467, 23°C	83.1	2.1
CTC Liftgate, Flow, 23°C	71.4	15.1
CTC Liftgate, Cross-Flow, 23°C	38.3	14
CPI Liftgate, Flow, 23°C	87C	19

Creep

All creep experiments were conducted at Datapoint Labs in Ithaca, NY. Standard ASTM 638 (12.5 mm reduced section) tensile bars of the CTC liftgate material were tested first. Creep results for the CTC liftgate material in the flow direction at 23°C are shown in Figure 4.

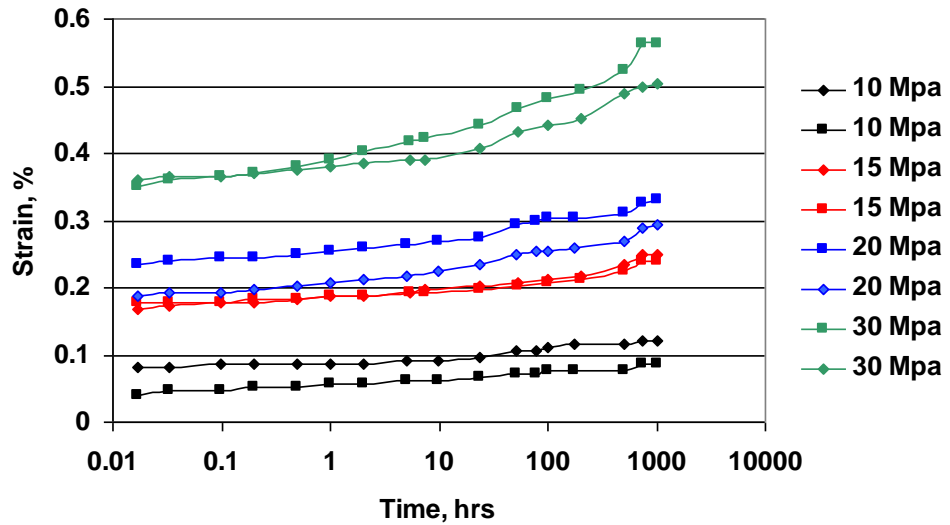


Figure 4. Tensile creep curves for CTC liftgate material in flow direction, 23°C.

Two samples were tested at each load level. The lowest load level of 10 MPa was 14% of the failure stress and the highest load of 30 MPa was 41% of the failure stress. The 10, 15 and 20 MPa samples increase linearly with log time, where as, the 30 MPa samples show a nonlinear response to time, indicating these samples may stress rupture with increased time. One way to get a better measure of the potential for stress rupture is to plot the data as an isochronous stress-strain curve, Figure 5 [5].

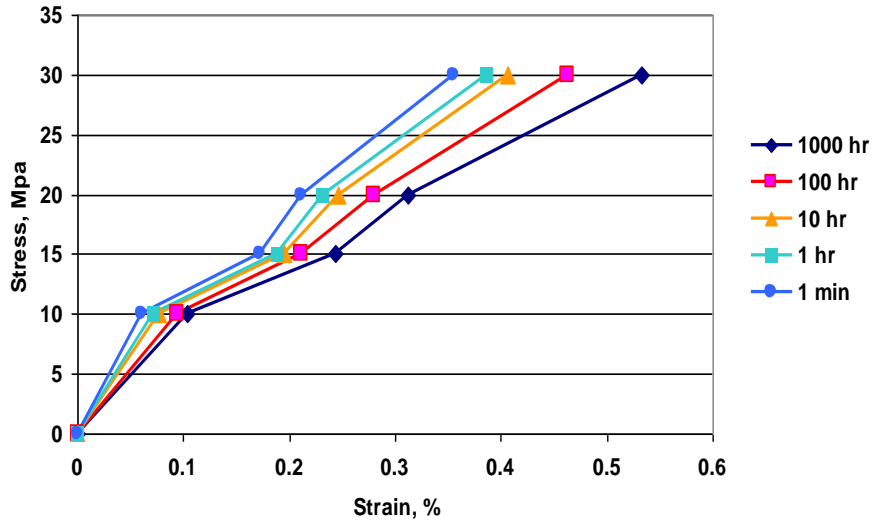


Figure 5. Isochronous stress-strain curves for CTC liftgate material in flow direction, 23°C.

If the time plots are linear with strain, stress rupture is not imminent, however, if the time curve is nonlinear, stress rupture is probable with greater load and time. The Isochronous curves for the CTC liftgate material are not smooth; however, the 1000 hr curve is slightly more nonlinear than the other time curves. Longer time and higher stress levels could lead to stress rupture.

The tensile creep curves for the CTC liftgate material in the cross-flow direction at 23°C are shown in Figure 6 and the isochronous curves in Figure 7.

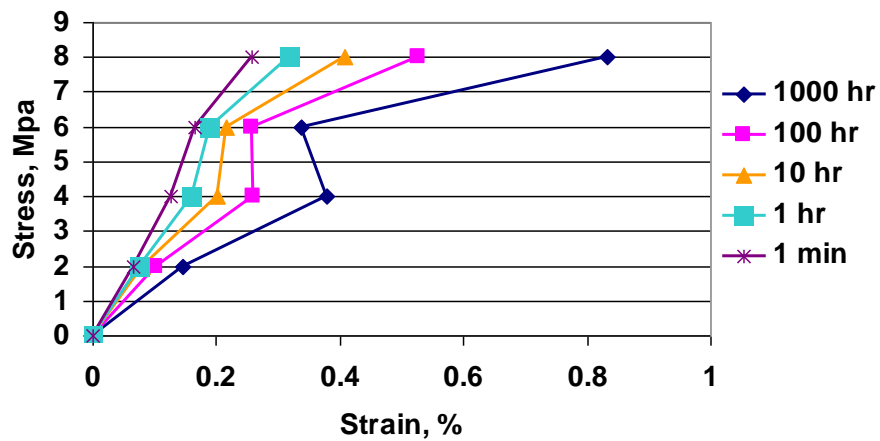


Figure 6. Tensile creep curves for CTC liftgate material in cross-flow direction, 23°C.

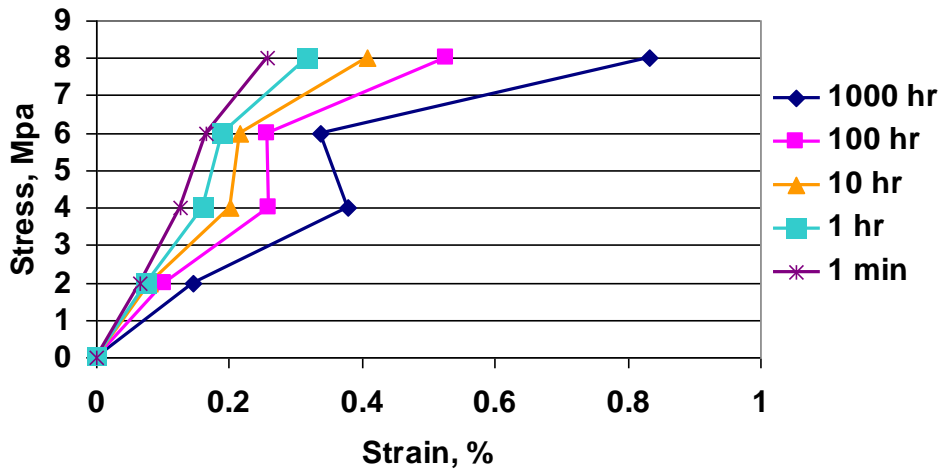


Figure 7. Isochronous stress-strain curves for CTC liftgate material

Based on the isochronous curves, it appears the strain measurements at 6 MPa are incorrect. Neglecting the data at 6 Mpa, Figure 8, only at the lowest times (7 hrs or less) do the curves appear to be linear, indicating all the cross-flow samples will stress rupture with higher stress and longer creep times.

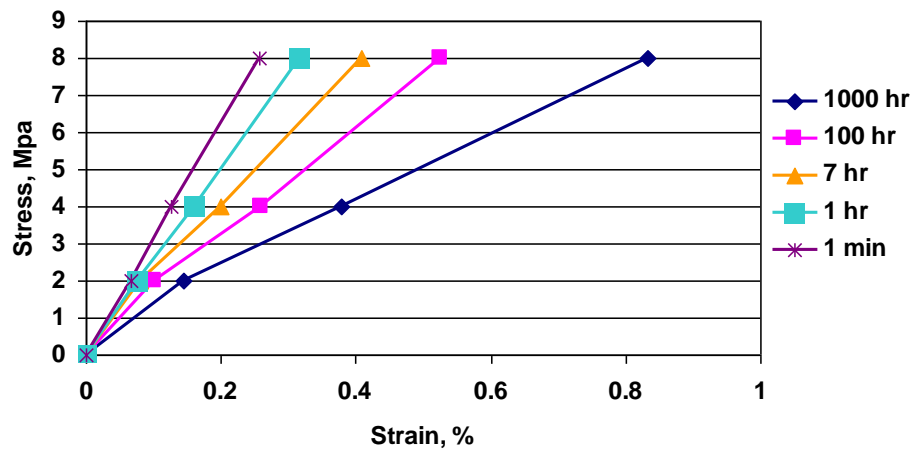


Figure 8. Isochronous stress-strain curves for CTC liftgate material in cross-flow direction, 23°C, 6 MPa data removed.

The 80°C tensile creep flow and cross-flow data are shown in Figures 9 and 10 and the isochronous plots in Figures 11 and 12. The two cross-flow samples at 5 MPa (Figure 10) show considerable scatter, resulting in inflection in the isochronous plot (Figure 12). At all the load levels used, the 80°C isochronous plots indicate stress rupture has occurred or will occur with increasing time.

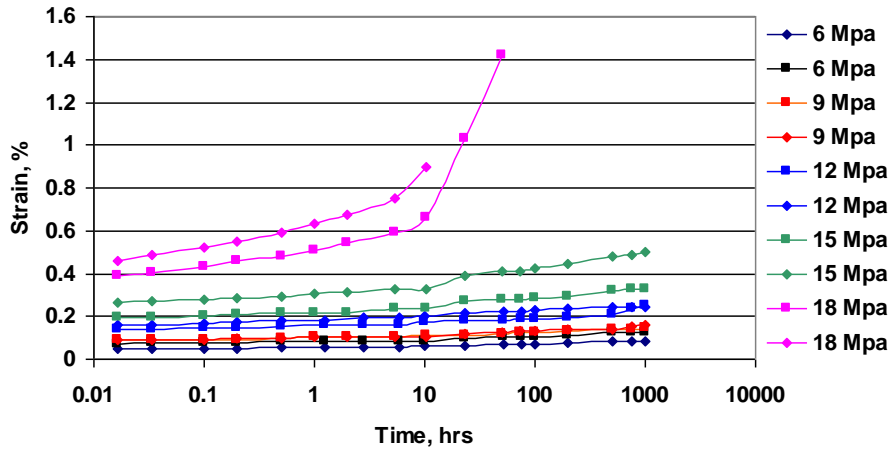


Figure 9. Tensile creep curves for CTC liftgate material in flow direction, 80°C.

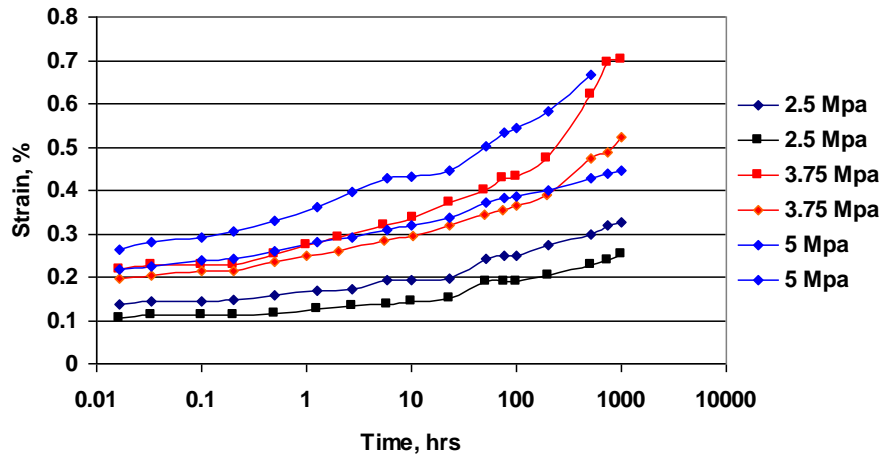


Figure 10. Tensile creep curves for CTC liftgate material in cross-flow direction, 80°C

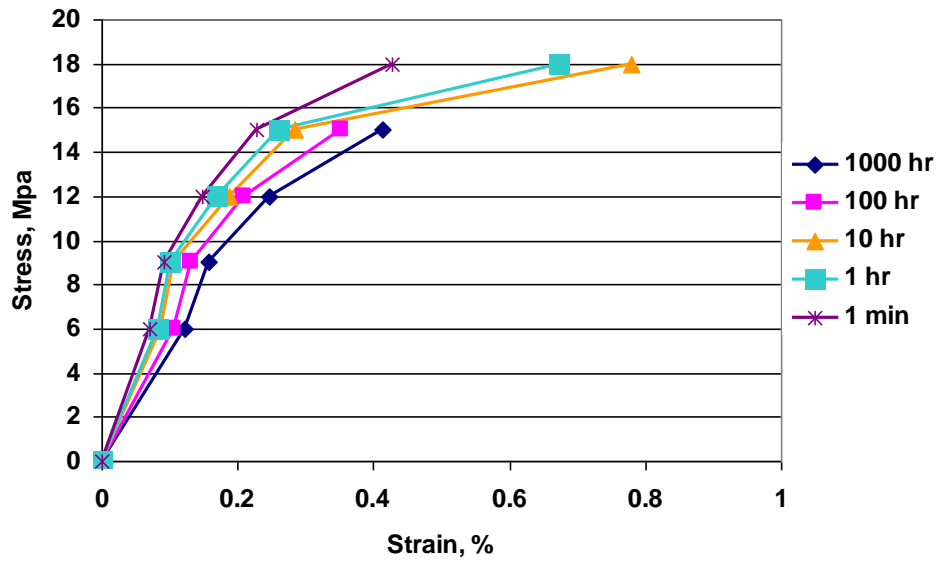


Figure 11. Isochronous stress-strain curves for CTC liftgate material in flow direction, 80°C

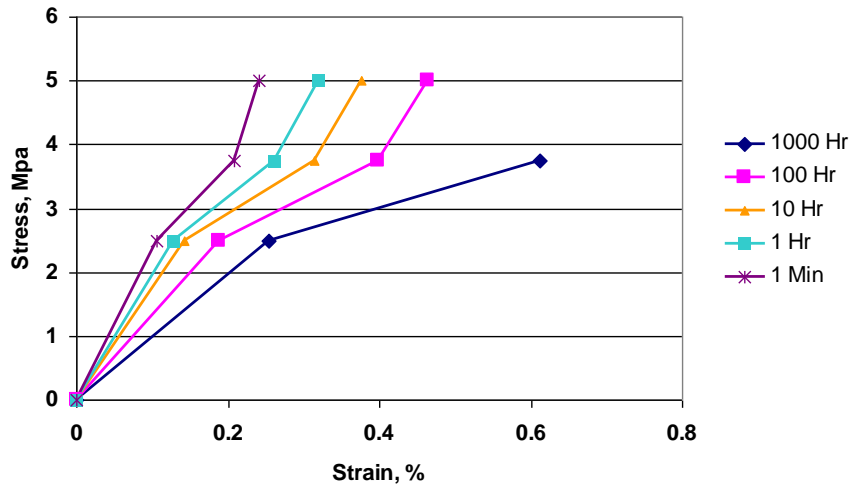


Figure 12. Isochronous stress-strain curves for CTC liftgate material in cross-flow direction, 80°C.

A second set of tensile bars to Datapoint Labs. These tensile were made using GMT R401, a continuous random glass mat containing 60% by weight PP. Both the liftgate material and the GMT R401 material contain the same % glass, however, the GMT R401 glass is much more uniform in concentration throughout the tensile bars. Four samples were used for each load level at 23°C and 80°C. The tensile creep curves for the GMT 401 material are shown in Figures 13 and 14 and the isochronous plots in Figures 15 and 16, the data indicates that over the load range of 15 to 40 MPa stress rupture of the GMT material is not imminent. Only at 40 MPa (32% of the failure stress) and 23°C is there any nonlinearity (Figure 15).

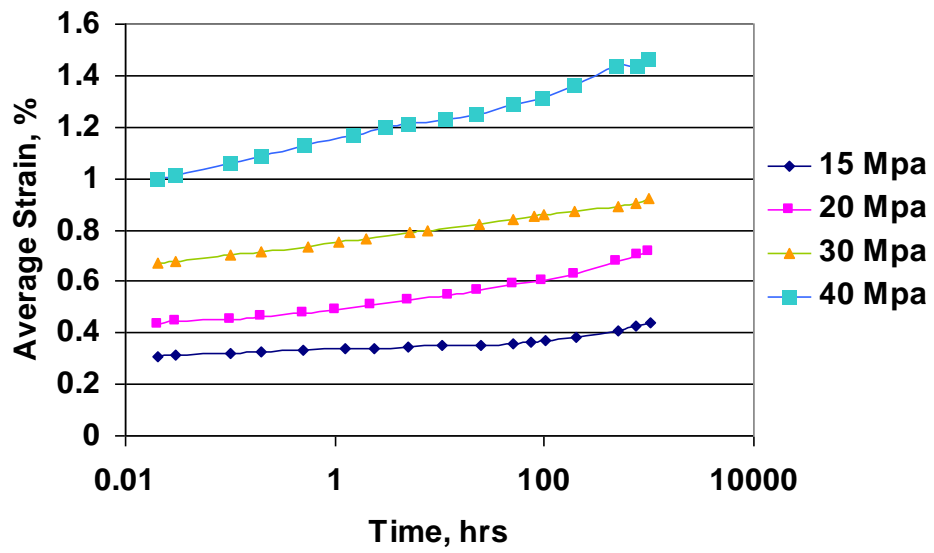


Figure 13. Tensile creep curves for GMT R401, 23°C

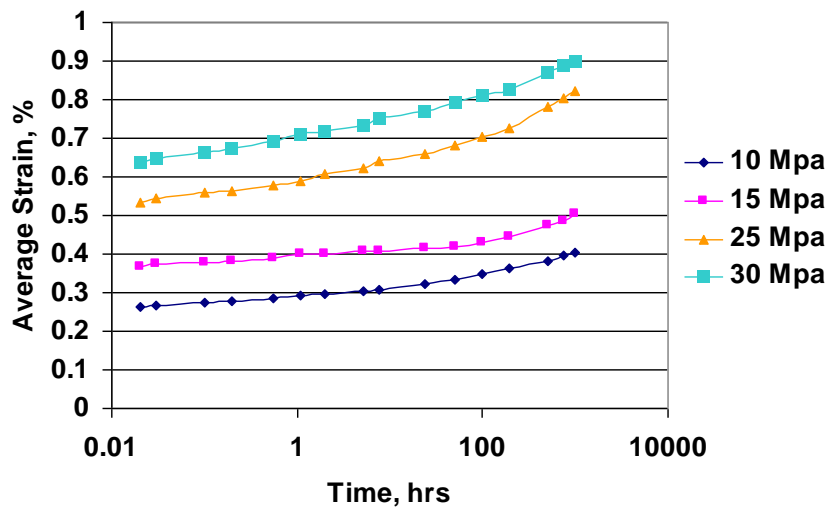


Figure 14. Tensile creep curves for GMT R401, 80°C

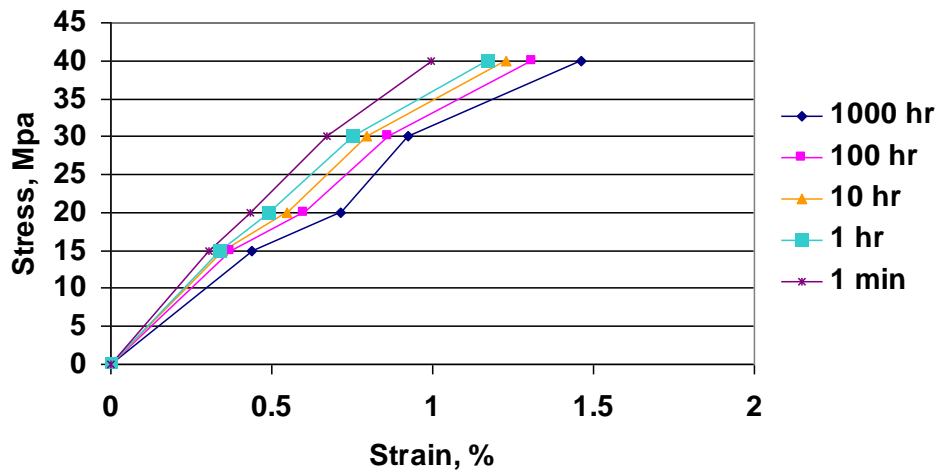


Figure 15. Isochronous stress-strain curves for GMT R401, 23°C.

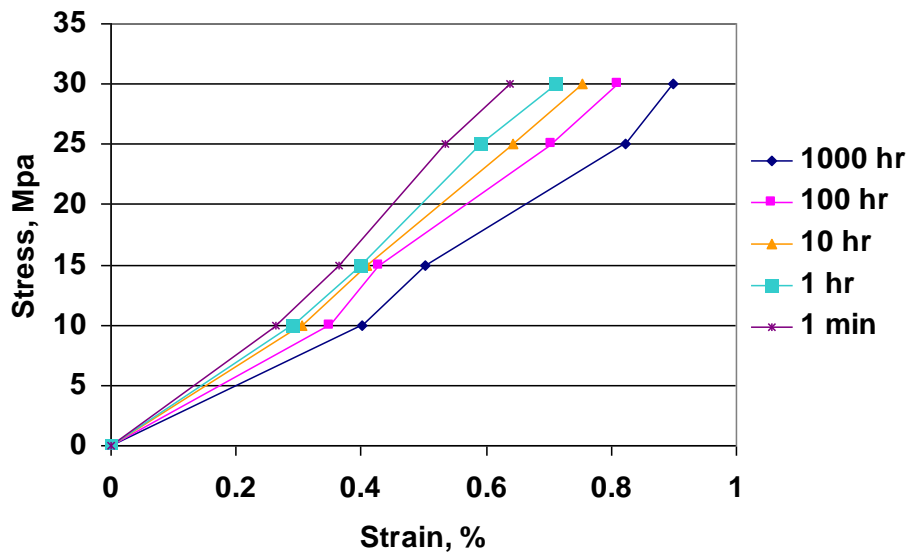


Figure 16. Isochronous stress-strain curves for GMT R401, 80°C,

The creep response for GMT R401 and CTC liftgate material in the flow direction are similar (Figures 4 and 13); however the strain at a given load is about two times higher for the GMT material. Finally, GMT R401 is less sensitive to temperature than the CTC liftgate material (Figures 11 and 16).

Fatigue

As stated earlier, many automotive parts undergo fatigue. The materials being analyzed here have been used to make liftgates. One test where fatigue is important is liftgate slam durability where the liftgate is opened and closed for 3 life cycles. Cyclic tensile-tensile fatigue tests were performed on these materials to determine their sensitivity to cyclic loading. Since most fatigue work on thermoplastic composites has been performed using very short glass fibers (0.01 to 0.1 mm) [3,4] compared to these materials which contain glass fibers 12 mm and longer, two sizes of tensile bars were used to determine if sample width affected the results. All fatigue tests were performed using an Instron 8501 servo hydraulic test machine in a tensile-tensile mode. The load was applied as a sine wave at 3 Hz with the minimum load set at 10% of the maximum load. Cyclic fatigue at rates greater than 3 Hz can lead to heating of composite test specimens [3].

Figure 17 shows the fatigue results in the form of an S-N plot for GMT R401 tensile bars with a 38 mm reduced section. Typically, there is a high degree of scatter between samples at a given load. Here three samples were tested at each load level. The linear regression fit and its R^2 value of 0.9186 indicate a very good linear fit between stress and cycles to failure. S-N curve for GMT R401 bars with a reduced section of 12.5 mm is shown in Figure 18; S-N curve for GMT C467 bars with a reduced section of 38 mm is shown in Figure 19; and S-N curve for the CPI liftgate material at 38 mm reduced section is shown in Figure 20. The only poor linear fit was for the CPI liftgate material, however, only a small number of samples were tested.

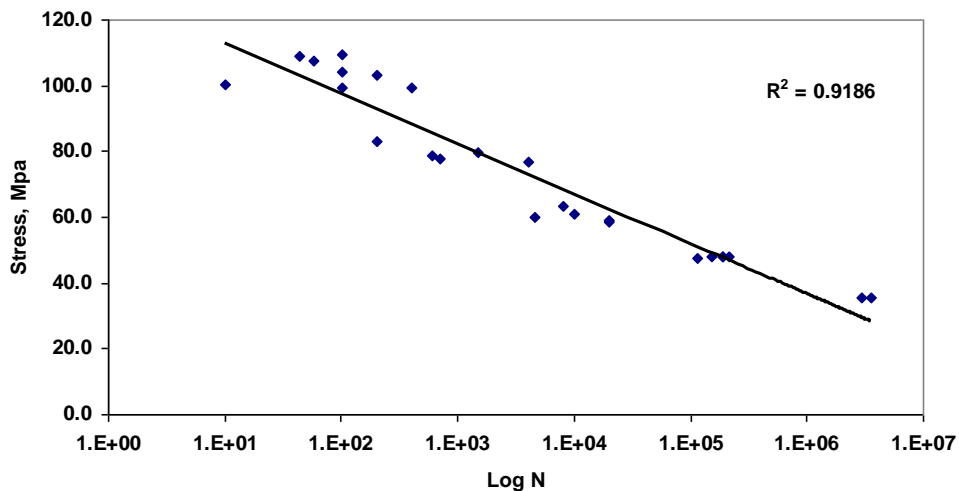


Figure 17. S-N curve for GMT R401, 38 mm bars.

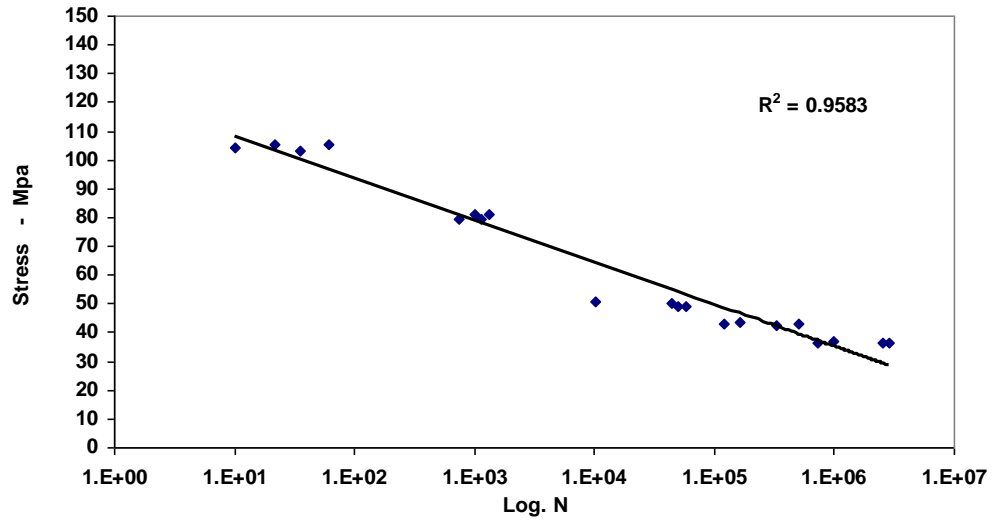


Figure 18. S-N curve for GMT R401, 12.5 mm bars.

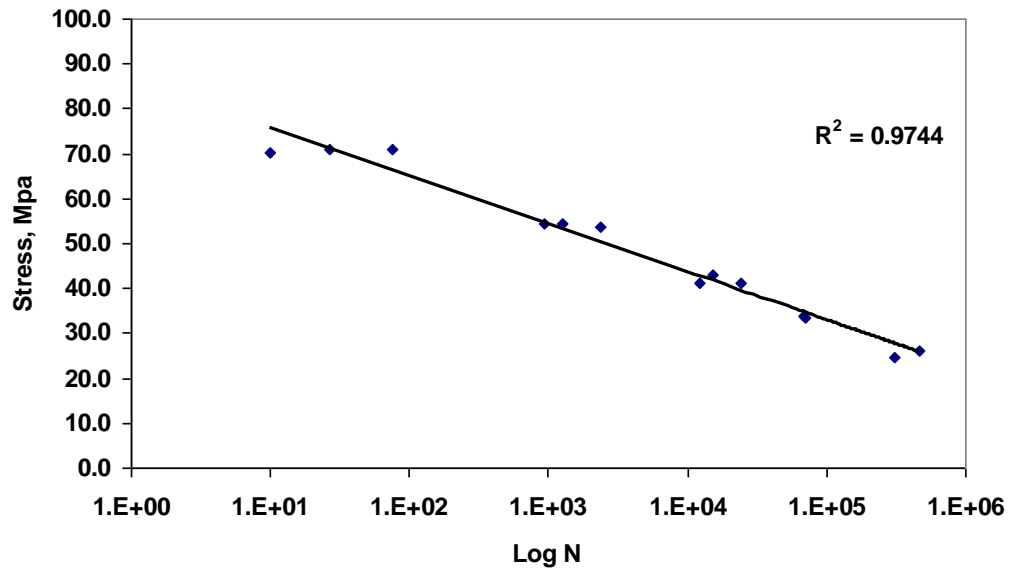


Figure 19. S-N curve for GMT C467, 38 mm bars.

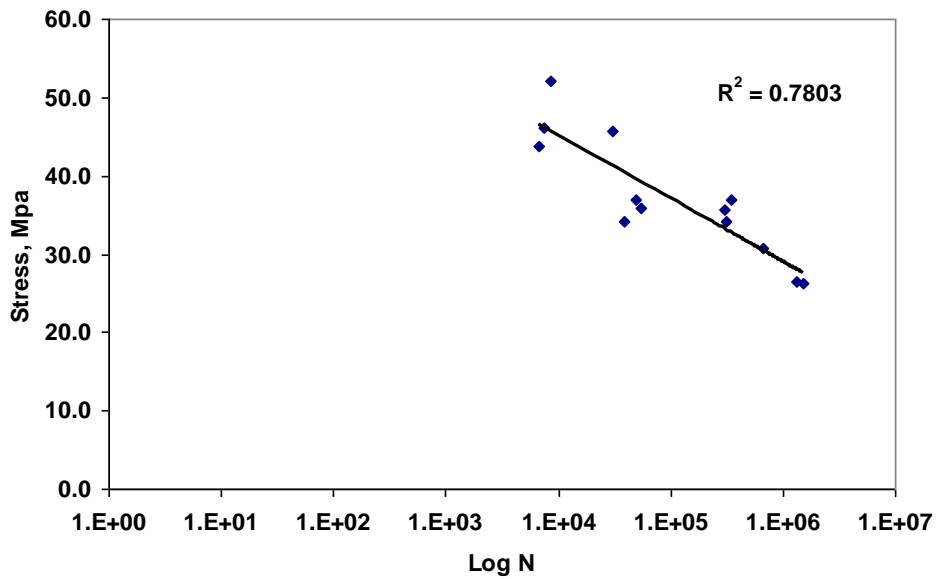


Figure 20. S-N curve for CPI liftgate material, 38 mm bars.

One way to compare these results is to generate an S-N curve for all the materials. In Figure 21, the fatigue results were normalized by the failure stress for each material (Table 1). All materials can be fit to one curve with a R^2 value of 0.9405. This means there are no major differences between the four data sets. Glass length and the presence of talc in the PP compounds affect the overall strength but do not affect the fatigue characteristics of the PP compounds. Also, sample width does not appear to be a factor.

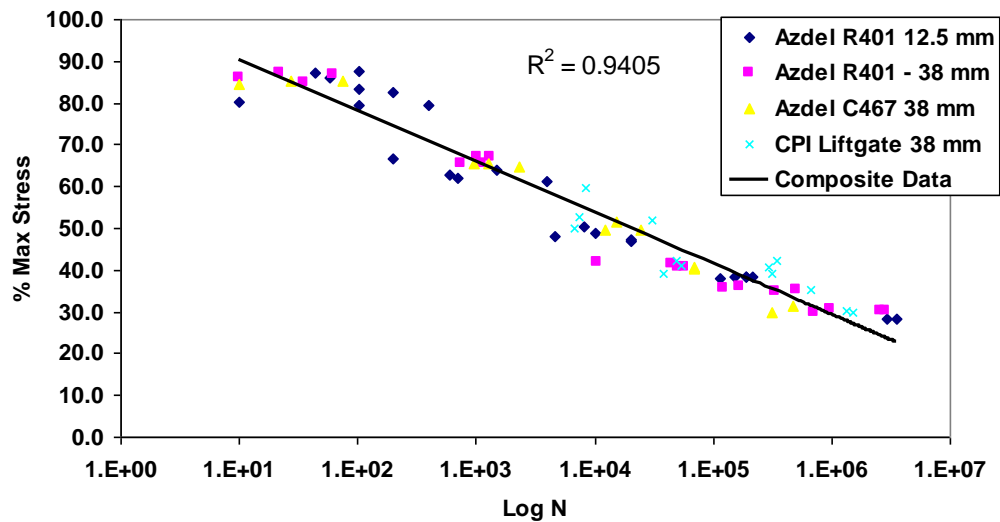


Figure 21. S-N curve for all long glass polypropylene materials.

Fatigue displacement or strain data can also be plotted against log cycles. In Figure 22, GMT R401 displacement data for the three loading levels was plotted versus log cycles. Just before failure, displacement increases rapidly indicating creep is occurring as the fatigue test progresses. This curve looks similar to the creep curves for GMT R401, Figure 13, indicating the failure mode for creep and fatigue may be the same.

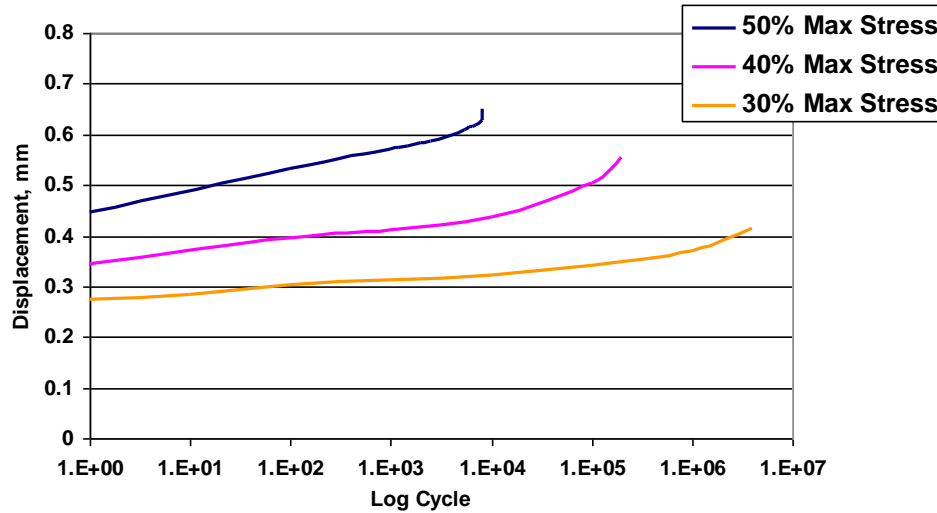


Figure 22. Fatigue displacement curves for GMT R401, 12.5 mm bars.

Summary

Typically, load levels for composite structures are kept to 25 to 30 % of the failure stress. The creep and fatigue data reported here for the long glass PP composite material are consistent with these guidelines. Creep data for the GMT R401 and CTC liftgate material in the flow direction show the potential for creep rupture at greater than 30% of the tensile failure strength. CTC liftgate material in the cross-flow direction is somewhat weaker than the flow direction with nonlinear response as low as 20%. When designing a part care should be taken about introducing a creep situation in the cross-flow direction.

The composite fatigue data curve (Figure 21) showed the fatigue results can be normalized by tensile strength and that glass length and the presence of talc in the PP compounds do not affect the fatigue characteristics of the PP compounds. Another general guide line for fatigue data is at least one million cycles are needed for good material fatigue characteristics and this occurs at 30% of the tensile strength for the PP compounds. The ability to use tensile strength to determine fatigue limits is important since some material suppliers do not provide tensile modulus information.

References

1. European Alliance for Thermoplastics Composites (EATC), www.eatconline.org.
2. Foss, P.H., Mentzer, C.C., Franklin, D.W., "Design and Validation of a Thermoplastic Composite Liftgate", Proceedings of the SPE Automotive Composites Conference, September 2004.
3. Wyzgoski, M.G., Krohn, J.A., and Novak, G.E., "Fatigue of Fiber-Reinforced Injection Molded Plastics. 1: Stress-Lifetime Data", Polymer Composites, Oct. 2004, Vol. 25 No.5, 489-498.
4. Wyzgoski, M.G., and Novak, G.E., "Predicting fatigue S-N (stress-number of cycles to fail) behavior of reinforced plastics using fracture mechanics theory". Journal of Material Science, January 2005, vol. 40 No. 2, 295-308.
5. Moore, D.R., and Turner, S., "Mechanical Evaluation Strategies for Plastics", Woodland Publishing, 2001, pp 250-274.