# Loading Rate and Temperature Dependence of Flexural Behaviour of GFPP Fabricated by Injection Molding Method

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## ABSTRACT

The mechanical behavior of polymer resins heavily depends on time and temperature, in a manner which is termed viscoelastic behavior. It is therefore presumed that the mechanical behavior of fiber-reinforced plastics (FRPs) fabricated by injection molding also depends on time and temperature because of the viscoelastic behavior of the matrix resin. The flexural static behavior of GFPP bars were evaluated at several levels of loading rates and constant temperature. The flexural static behavior was found to be remarkably dependent on time and temperature. Clearly, the flexural static behaviors of the GFPP dumbbell were dominated by the viscoelastic behavior of the matrix resin.

## 1 INTRODUCTION

Recently glass fiber reinforced plastics (GFRP) has been used for the primary structures of airplanes, spacecraft and others, in which the high reliability should be kept during the long operating period. Therefore, it is strongly expected that the accelerated testing methodology is established for the long-term life prediction of composite structures exposed under the actual environment of temperatures, water and others.

In this paper, the flexural static modulus of two types of GFPP fabricated by injection molding method were measured at several levels of loading rates and constant temperatures. One type is "Wet" GFPP that has been immersed in hot water at 80 ℃ for 300 hours and dried at 100 ℃ for 2 hours in the oven, another one is "Dry" GFPP that not immersed in hot water. GFPP dumbbells were fabricated by injection molding process, screw speed of injection unit was fixed at 180 rpm and the molding temperature was set at 240℃. Three point flexural static tests for these two types of specimens were conducted by using an Instron type testing machine with a constant temperature chamber. The testing temperature conditions ranged from room temperature 25 ℃ to 120 ℃, the constant deflection rates were from 0.01 to 10 mm/min. The nominal thickness, width and length of all specimens were 3, 10, and 60 mm, the span was 48 mm. Modulus was calculated according to the Japanese Industrial Standard (JIS) K7074.

## 2 EXPRIMENTAL PROCEDURE

### Specimens Preparation

The pre-compounded glass fiber polypropylene pellet (25wt %) was supplied by Sumitomo Chemical Co., Ltd, Japan. The glass fiber pellets were added into feeding unit of injection machine and the screw speed of injection unit was fixed at 180 rpm. The injection temperature was set at 200-270℃ with 60 ℃ cooling temperature and 20 second cooling time. All specimens were injected into dumbbell-shaped bars by 30 tons injection machine. The thickness and width of the specimens are 3 mm and 10 mm.

The GFPP dumbbell specimens were prepared under two conditions of "Dry" and "Wet". Details of specimen conditions are shown in Table 1. The "Dry" dumbbells were obtained by holding the GFPP specimens in oven at 100℃ for 2 hours. The "wet" dumbbells were obtained by soaking the Dry specimens in hot water at 80℃ for 300 hours and then dehydrating these wet specimens in the oven at 100℃ for 2 hours.

Table 1 Specimen conditions for "Dry" and "Wet+Dry" dumbbells

| | In Oven | → | In water | → | In Oven |
|---|---|---|---|---|---|
| Dry | 100℃ ×2h | | — | | — |
| Wet | 100℃ ×2h | | 80℃ ×300h | | 100℃ ×2h |

### Test Procedures

Three point flexural static tests for "Dry" and "Wet" GFPP dumbbells were conducted by using an Instron universal testing machine with a constant temperature chamber. As shown in figure 1, The testing temperature conditions range from 25℃ to 120 ℃, While the constant deflection rates were 0.1mm/min, 1mm/min, and 10 mm/min respectively.

Table 2 CSR test conditions

| Material | Loading Rate V(mm/min) | Test Temperature T(℃) |
|---|---|---|
| Dry | 0.1, 1, 10 | 25, 40, 60, 80, 100, 120 |
| Wet | 0.1, 1, 10 | 25, 40, 60, 80, 100, 120 |

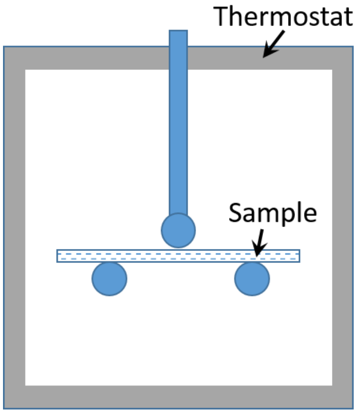


Figure 1 Experimental system

Modulus was calculated according to the Japanese standard JIS K7047, Time to failure t for the static test was calculated using:

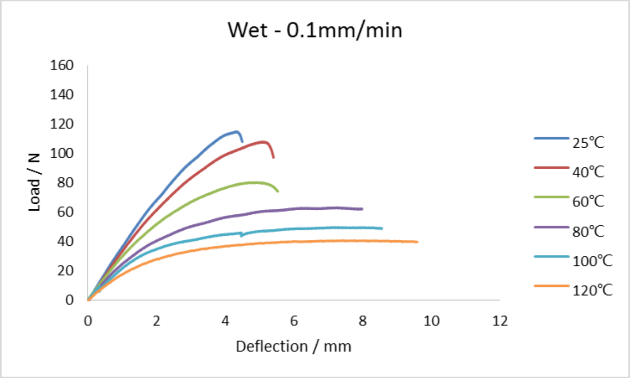
$$t = \frac{\delta_{max}}{v} \tag{1}$$

Where $\delta_{max}$ and $v$ are the deflection at the maximum stress and the testing deflection rate.

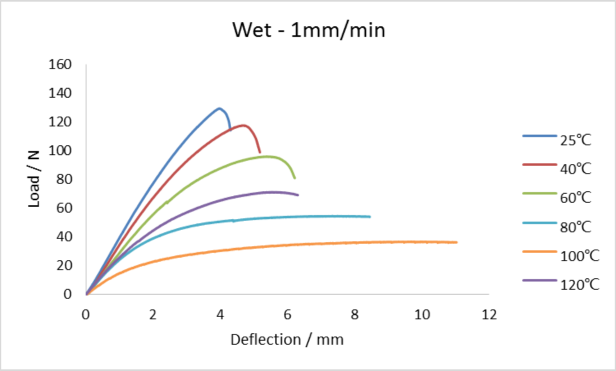
## 3 RESULTS AND DISSCUSSION

### Load-deflection Curve of GFPP Specimens

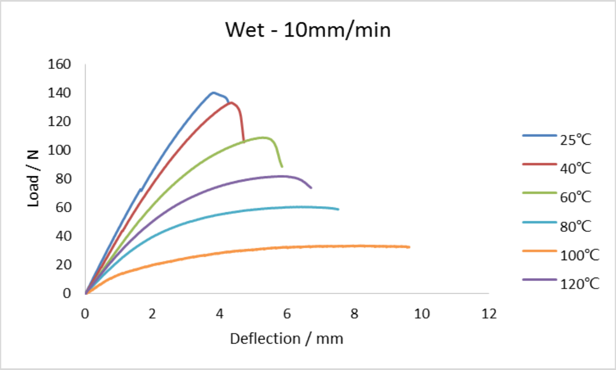
The load-deflection curve of GFPP shows the nonlinear behavior of load rising slowly when the load exceeds the knee point. As shown in figure 2 and figure 3, with the increase of temperature, the maximum failure load decreases and the maximum deflection increases gradually. While with the increase of loading rate from 0.1mm/min to 10mm/min, the maximum failure load increases and the maximum deflection decreases gradually. It means that the flexural behavior of GFPP composites molded by injection methods remarkably depends on the loading rate and temperature.



（a）Wet specimens at the speed of 0.1mm/min

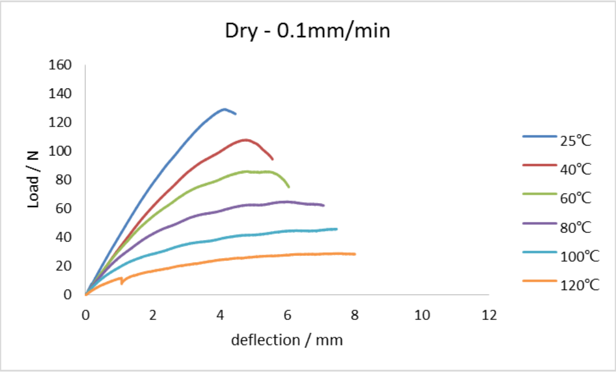


(b) Wet specimens at the speed of 1mm/min

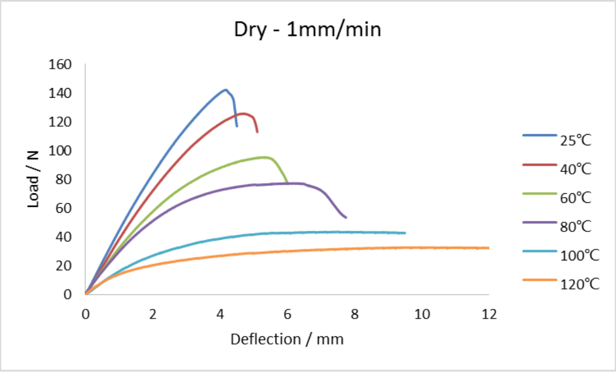


(c) Wet specimens at the speed of 10mm/min

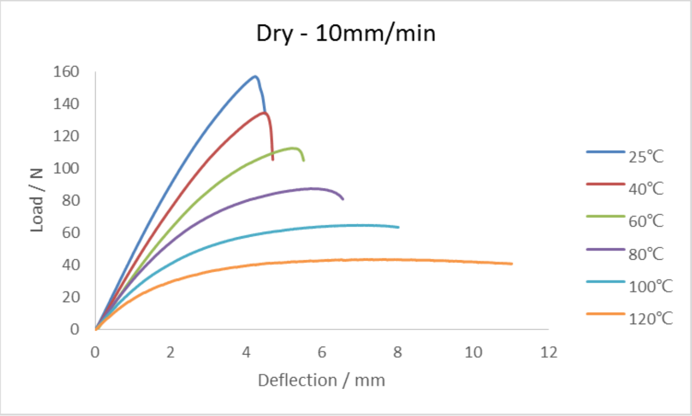
Figure 2 Load-deflection curves of the wet GFPP specimens



(a) Dry specimens at the speed of 0.1mm/min



(b) Dry specimens at the speed of 1mm/min



(c) Dry specimens at the speed of 10mm/min

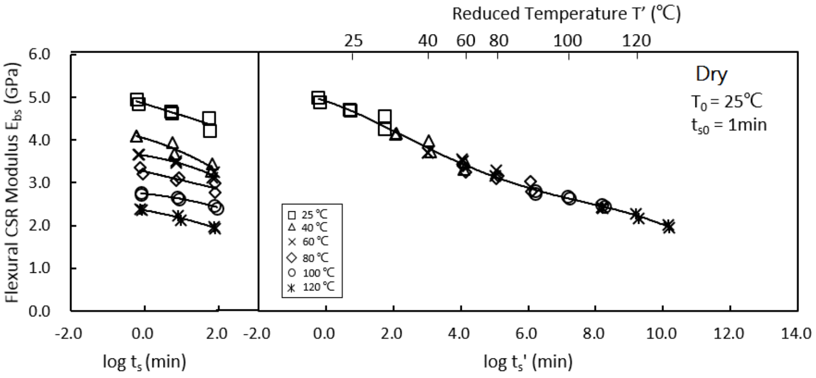
Figure 3 Load-deflection curves of Dry GFPP dumbbells

## Master Curve of Flexural CSR Modulus for Two Types of GFPP

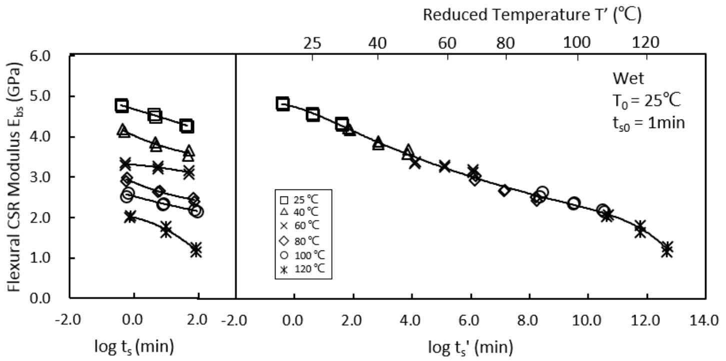
Figure 4 shows the master curves of flexural static modulus $E_{bs}$ versus reduced time t' at a reference temperature of $T_0$=25℃ for two types of GFPP specimens. Each of the figures in Figure 4 shows two graphs. The left side is the flexural static modulus $E_{bs}$ versus time to failure at various temperatures *T*, and the right side is the master curve of flexural static modulus $E_{bs}$ versus reduced time *t'*. The graphs on the left side show that the flexural static modulus $E_{bs}$ of GFPP depends on time to failure *t* and temperature *T*. The flexural static modulus $E_{bs}$ master curves were constructed by shifting $E_{bs}$ at the various constant temperatures *T* along the log scale of time *t* until they overlapped. The flexural static modulus $E_{bs}$ at temperatures below the reference temperature $T_0$ were shifted horizontally to the left, while the flexural static modulus $E_{bs}$ for temperatures higher than $T_0$ were shifted horizontally to the right. The horizontal time and temperature shift factor $a_{T_0}(T)$ is defined as follows:

$$a_{T_0}(T)=\frac{t}{t'} \tag{2}$$

Since flexural static modulus $E_{bs}$ at various temperatures can be superimposed so that a smooth curve is created, the time-temperature superposition principle is applicable.



(a) Master curve of "Dry" specimen



(b) Master curve of "Wet" specimens

Figure 4 Master curve of flexural CSR modulus for "Dry" and "Wet" GFPP dumbbell

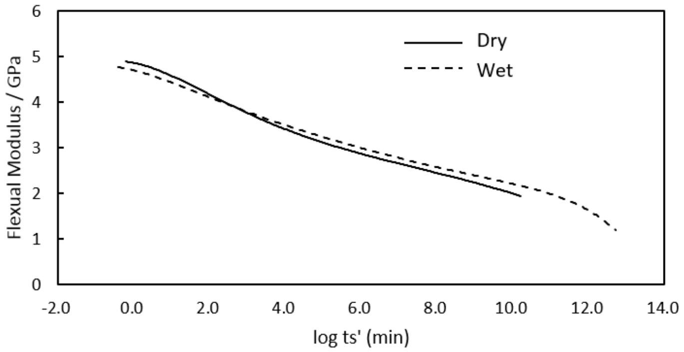


Figure 5 Flexural modulus comparison of two types of master curve

Figure 5 shows the Flexural modulus comparison of two types of master curve. It is found that the flexural static modulus of "Wet" is almost same with "Dry", that means soaking in hot water for 300 hours has little effect on GFPP fabricated by injection molding method.

Figure 6 shows the time-temperature shift factors $a_{T_0}(T)$ obtained experimentally for the master curve of flexural static modulus. The shift factors $a_{T_0}(T)$ are in good quantitative agreement with Arrhenius' equation, so the shift factors for GFPP can be approximated by using two different activation energies $\Delta H$:

$$\log a_{T_0} = \frac{\Delta H}{2.303R}\left[\frac{1}{T}-\frac{1}{T_0}\right] \tag{4}$$

Where: $\Delta H$ = activation energy [kJ mol$^{-1}$]; R = gas constant [=8.314 × $10^{-3}$ kJ K$^{-1}$mol$^{-1}$]; T = testing temperature [K]; and $T_0$=reference temperature [K].

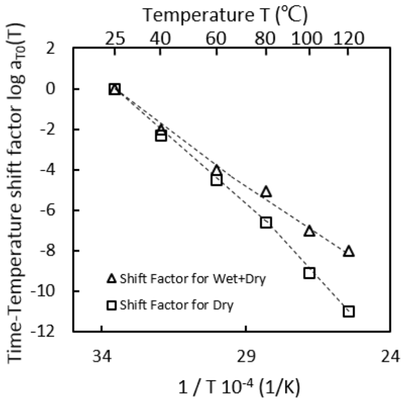


Figure 6 Time-temperature shift factors and activation energies for the GFPP composites

The results shows that the shift factor variation trend of "Dry" and "Wet" are very similar in the initial time (low temperature), while the "Dry" is difference from "Wet" when the temperature is above 80 ℃. It can be considered that this is due to the damage generated in the composites during water absorption.

## 4 CONCLUSIONS

The flexural static modulus of GFPP composites fabricated by injection molding are measured at several levels of loading rates and constant temperatures. It is depends on loading rate and temperature remarkably and shows the viscoelastic behavior. The following conclusion can be obtained:

(1) The time-temperature superposition principle is applicable to the GFPP specimens that treated by 300 hours hot water soaking, and the master curves of flexural CSR modulus for all GFPP composite can be constructed.

(2) 300 hours of hot water socking has a little effect on flexural constant static modulus of GFPP fabricated by injection molding.

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