FLOW ANALYSIS of an INJECTION MOLDED HIGHLY FILLED SHORT GLASS FIBER REINFORCED POLYMER (GFRP) BULK MOLDING COMPOUND (BMC)

Michael C. Faudree[1*] and Yoshitake Nishi[1]

[1] *Department of Material Science Engineering, Tokai University, 4-1-1 Kitakaneme, Hiratsuka 259-1292, Japan.*
*Corresponding author (fm67434@tsc.u-tokai.ac.jp)

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Introduction

Glass fiber reinforced polymer bulk molding compounds (GFRP-BMCs) are composites that have wide application in aerospace, automotive parts, housing for electrical wiring, and corrosion resistant needs. They have excellent flow characteristics that make them well suited for injection molded parts requiring precise dimensions and detail hence different methods of analyzing flow are important. Flow analysis through a dog-bone shaped specimen with rectangular cross section is performed on the typically highly viscous 3-phase GFRP-BMC consisting of 20 mass% short glass fibers with ~0.44 mm in average length and ~11 μm in diameter, propylene glycol maleate polyester/styrene butadiene copolymer, and a high 47.1 mass% of $CaCO_3$ filler exhibiting parabolic laminar creep flow with extremely low Reynolds number $Re = 2.44 \times 10^{-4}$[1]. Based on effective viscosity, $\eta_{eff,(avg)} = 70.8$ Pas of BMC paste at the mold walls that must be overcome by the injection pressures obtained from steady-state Navier-Stokes calculation in injection molding *z*-direction with friction factor, *f* of 5420, and P_{loss} of 20-40% of injection pressure, a parabolic wavefront was calculated [1].

It is determined the parabolic flow through the mold can be characterized by a simple method of first order graphical differential equation, $dv_z/dx = f(x)$ for not only the wavefront but the flow through the entire specimen. The flow is assumed to be stable throughout the specimen length since the thick boundary layer, $\delta_{0.99U_c}$ of laminar creep flow of the highly viscous GFRP-BMC is assumed to be stable. This $\delta_{0.99U_c}$ is traditionally defined as points where the velocity is 99% of the centreline velocity, U_c extending from mold walls [2]. The flow is also characterized to be stable by the calculated short entrance length, L_e (0.002 to 0.005% of total length)[1] at which $\delta_{0.99U_c}$ is stable throughout the specimen length assuming no backflow. These methods aim to be useful in mold design.

Results and Discussion

Figure 1 shows a flow direction field [3] can be constructed when the smooth parabolic velocity profile of GFRP-BMC through the mold is represented by the simple differential equation $dv_z/dx = f(x)$ written as $y' = kx/2$. Here *x*-axis is position from centerline of thickness and *y*-axis is arbitrary units maintaining same parabolic shape as velocity profile. The y' are slopes of direction field represented by the short lines of the paste flow following the parabola. Isoclines can be conveniently drawn as vertical lines where slopes are constant, $y' = C$, for example, $y' = -3k/4, -k/2, -k/4, 0, k/4, k/2$ and $3k/4$; at $x = -3/2, -1, -1/2, 0, 1/2, 1$ and $3/2$ mm, where for our conditions, the constant $k = -16U_c/th^2 = -2.85 \times 10^5$ $s^{-1}m^{-1}$. U_c is centerline velocity (=0.194 ms^{-1}).

Moreover, the flow direction field $y' = kx/2$ is easily solved by direct integration to $y = kx^2/4 + m$, where *m* is a constant, whose solution curves are a family of parabolas represented in Fig. 1 along the specimen length according to $m = 0$, $m = 1$, $m = 2$. Assuming steady-state flow with the low L_e and thick $\delta_{0.99U_c}$ of the BMC, the family of curves assumes not to change shape within the thin and thick sections ignoring the taper. Thus, for physical meaning, *m* is defined according to spacing between fibers, S_f. Since measured 1-dimensional number density of fibers, $N_f = 22.32\text{mm}^{-1}$, $S_f = 0.045$mm, $m = nS_f$ and *n* is a multiple of N_f. Therefore, we obtain predicted parabolic solution curves.

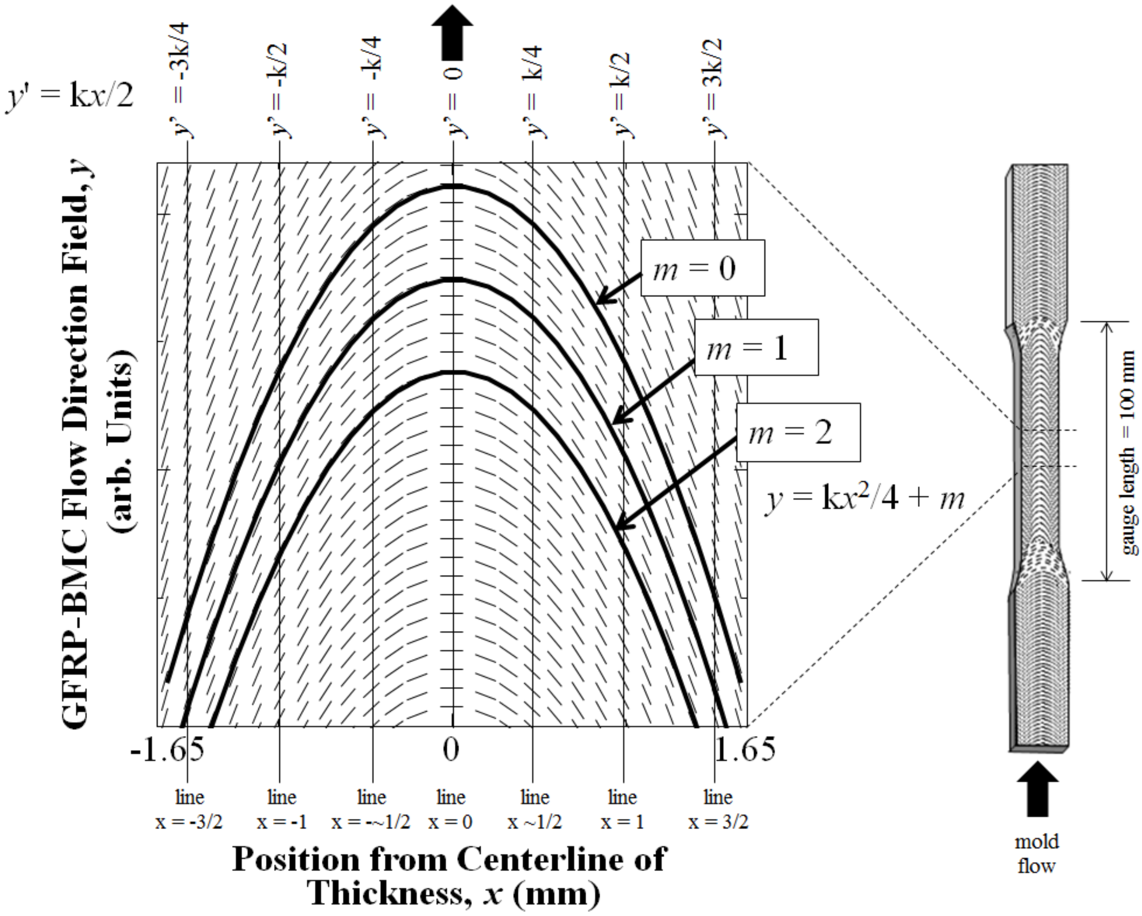

Figure 2: *GFRP-BMC mold flow through dogbone specimen is represented as a flow direction field with slopes, $y' = kx/2$ (short lines) and its direct integration curves, $y = kx^2/4 + m$, where m is a constant, whose solution is a family of parabolas along specimen length. Note: small lines are not fibers.*

Conclusions

For a widely used highly viscous glass fiber reinforced polymer bulk molding compound (GFRP-BMC) with 47% $CaCO_3$ filler, parabolic flow through the mold is characterized by a simple new formula of first order graphical differential equation flow direction field, $y' = kx/2$ with solution curves $y = [kx^2/4] + m$ for wavefronts through the entire specimen. The new flow analysis method aims to be useful in injection mold and processing design.

References

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