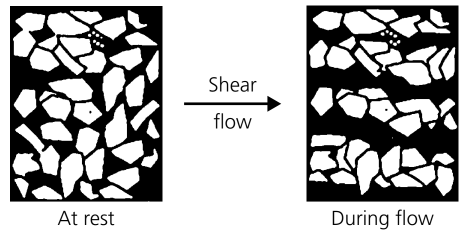

Figure 11.4 Schematic diagram of particles within a suspension at rest and during flow.

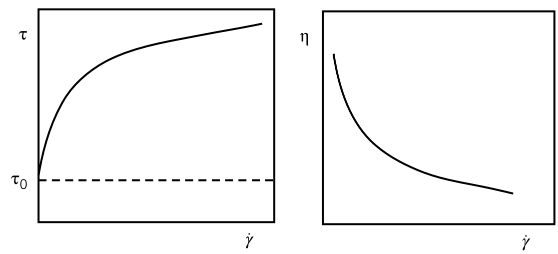

Figure 11.5 Shear stress – shear rate and apparent viscosity – shear rate relationship for shear thinning materials.

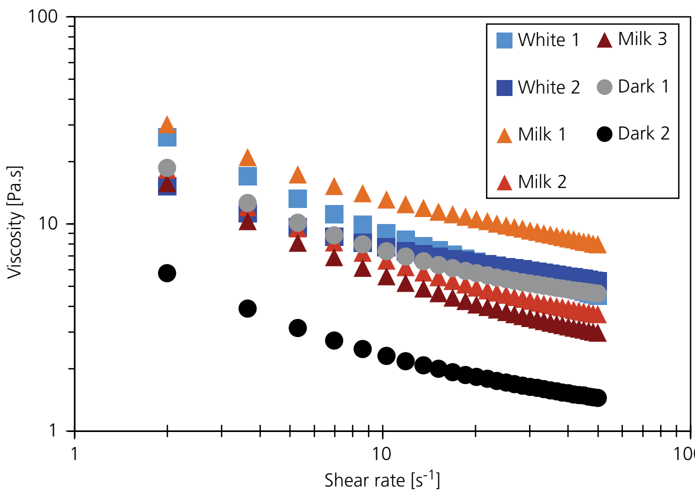

Figure 11.6 Flow measurements on a variety of liquid chocolates.

the flow induced structure has reached a pseudo equilibrium. The material behaviour is referred to as shear thinning. The corresponding plots of shear stress and apparent viscosity against shear rate are shown in Figure 11.5.

The shear stress at which the flow starts τ_o is often referred to as the yield value and is particularly important for enrobing or dipping chocolates, where the movement is slow and hence there is a low shear rate (Figure 11.5).

Figure 11.6 illustrates the apparent viscosity of commercial molten chocolates analysed in the shear rate range of 5–50 s^{-1} at a temperature of 40 °C. This shows that the viscosity decreases significantly with increasing shear rate and therefore the shear rate applied for analysis must relate to factors such as the processing conditions. Usually the shear rate is very high during depositing, but low for the removal of bubbles from a mould. This means that, when the viscosity of a chocolate is specified, more than one figure is normally needed.

11.3 Presentation of viscosity measurements

Presenting the viscosity of a chocolate as a curve, such as is shown in Figure 11.6, is not very helpful when trying to specify a chocolate from a supplier or to determine whether it has been giving production problems. Provided that the measuring technique is carefully controlled and the same shear rates are applied, the apparent viscosity can be used. The International Office of Cocoa, Chocolate and Sugar Confectionery recommend that the apparent viscosity should be reported in at least five points, so as to cover the low, medium and high shear rate ranges (OICCC, 2000). In practice most chocolates can be characterised by two measurements, one at about 5 s^{-1} for low flow situations and to approximate to the yield value and a second one between 10 and 20 s^{-1} for higher flow rates.

An alternative method of expressing the viscosity is to fit a mathematical equation to the flow curve for the liquid chocolate. There are a large number of these of varying complexity (Windhab, 1995), but the Casson model is the most widely used within the chocolate industry. Several variations of the model exist, some taking into account the configuration of the viscometer measuring system being used. The basic equation is:

$$\sqrt{\tau} = K_0 + K_1\sqrt{\dot{\gamma}} \tag{11.2}$$

K_0 and K_1 are constants which depend upon the viscosity of the chocolate being measured. This equation can be expressed in graphical form as is shown in Figure 11.7 and shows that, when there is a shear stress (τ) less than or equal to K_0 applied, no movement is taking place. This value is known as the Casson yield value ($\tau_c\alpha$). The gradient of the line, K_1, is equal to $\sqrt{\tau}/\sqrt{\dot{\gamma}}$, which using Equation 11.1 shows it to be the square root of the viscosity. The value of the slope of the line squared K_1^2 is known as the Casson plastic viscosity ($\eta_c\alpha$) which characterises the faster flow properties of the chocolate.

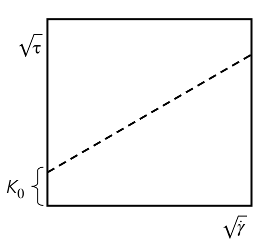

Figure 11.7 Viscosity plot for a Casson liquid.