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RHEOLOGY OF LATEX-MODIFIED GROUTS

M.L. Allan[1]
Department of Applied Science, Brookhaven National Laboratory, Upton, New York 11973

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ABSTRACT

The rheology of grouts containing latex was investigated. The two latex additives used were carboxylated styrene-butadiene and acrylic. The influences of superplasticizer, fly ash, and blast furnace slag on the rheology of latex-modified grouts were addressed. Shear stress-shear rate curves were determined for a variety of mix proportions. The time-dependent behaviour of selected grouts was also studied. It was determined that the yield stress and apparent viscosity are influenced by latex content and that the grouts are shear thinning at low water/cement ratios. Latex imparts stability and thixotropy in grouts. Partial replacement of cement with either fly ash or slag diminishes the effect of latex on rheology. © *1997 Elsevier Science Ltd*

Introduction

The pumpability and ability of cementitious grouts to penetrate voids and cracks is strongly dependent on the rheological behaviour of the grout. This is important in diverse grouting applications including ground treatment, repair of concrete, reduction of rock or soil permeability, environmental remediation, prestressing concrete, rock anchors, sealing radioactive waste repositories, and well completion. The addition of latex to grout formulations offers potential improvements in adhesion, impermeability, flexural and tensile strength, and resistance to chemical degradation. For example, latex-modified grouts have been investigated for use in post-tensioning ducts (1) and latex is sometimes added to oil well slurries (2,3). Latex has also been studied for improving the properties of cement-bentonite grouts used for mixing with soil (4). This paper examines the rheology of latex-modified grouts and the interactions with superplasticizer, fly ash, and ground granulated blast furnace slag.

[1]To whom correspondence should be addressed

Experimental

Materials

The cement used in the studied grouts was ASTM Type I. Liquid superplasticizer (SP) was added to improve flow properties. The superplasticizer contained 42% naphthalene sulphonate formaldehyde condensate and was used at a dosage of 20 mL/kg (0.32 fl.oz./lb) of total cementitious materials. This corresponds to a level of 1.0% solids by mass of total cementitious materials. Class F fly ash (FA), conforming to ASTM C 618–94a, was used as a supplementary cementing material in some of the grout formulations. The proportion of fly ash added was 40% by mass (cement + fly ash). Ground granulated blast furnace slag (BFS), conforming to ASTM C 989–89 Grade 100, was used to replace Type I cement at a level of 40% by mass. Due to the bleed reduction imparted by the addition of latex, it was not necessary to add bentonite to any of the grout formulations.

The two types of latex used were a carboxylated styrene-butadiene copolymer (SBR) (Tylac 68009–00, Reichhold Chemicals) and an acrylic (ACR) (Rhoplex MC76, Rohm and Haas). The styrene-butadiene latex had a polymer solids content of 42%. The polymer solids content of the acrylic latex was 46–48%. The styrene-butadiene latex already contained a silicone antifoam, whereas the acrylic did not. It was found that additional antifoam was required to control foaming of both latex types due to the type of mixing equipment used. Silicone antifoam (Dow Corning Antifoam B) was added to the grout formulations at a rate of 1% by weight of latex for the styrene-butadiene and at 3% for the acrylic. The latex content of the grouts is described throughout this paper in terms of polymer solids/cementitious material ratio (p/cm).

The water/cementitious material ratio (w/cm) was generally held constant at 0.45. Some experiments were performed to determine the effect of w/cm and values were increased to 0.55 and 0.60. Two polymer solids/cementitious material ratios, 0.05 and 0.15, were studied. Unmodified (p/cm = 0) grouts were tested for comparison.

Mixing

Grouts were prepared in a 1 litre capacity blender. The order of addition for p/cm = 0.05 and w/cm = 0.45 was water, antifoam, any fly ash or slag, cement, and latex. Superplasticizer was added either to the mixing water or after the latex in order to determine the effect of delayed addition on rheology. Grouts with p/cm = 0.15 and w/cm = 0.45 could not be mixed in the same order as that for p/cm = 0.05 due to the dryness of the mix. Hence, latex was added after mixing the water and antifoam. It is usually preferred to add latex after dry solids to prevent excessive air entrainment. The effect of adding superplasticizer to the mixing water instead of after the cement was also investigated for p/cm = 0.15 and w/cm = 0.45. For grouts with w/cm = 0.55 or 0.60, the order of addition was water, antifoam, superplasticizer, any fly ash, cement, and latex.

Rheology

Rheological properties were measured using a Fann 35A 6-speed coaxial cylinder viscometer. Grout was added to the viscometer immediately after mixing in the blender and the

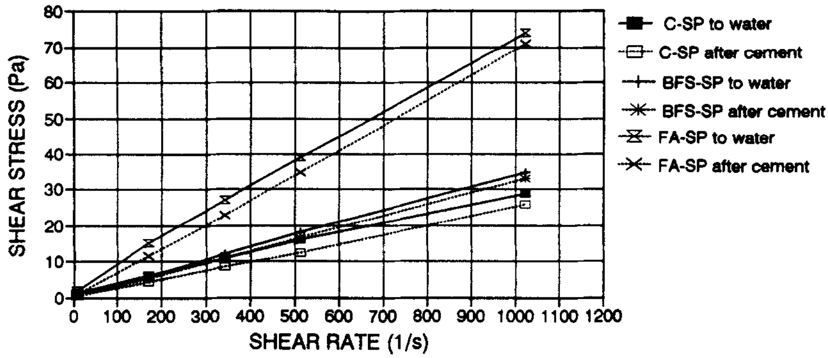

FIG. 1.
Shear stress vs. shear rate for unmodified grouts, w/cm = 0.45.

ambient temperature was 21°C. Shear stress-shear rate curves were determined using a procedure of progressive step decrease in shear rate. The grout was rotated for 60 s at a shear rate of 1021 s^{-1} (rotor speed = 600 rpm). The shear stress at 60 s was recorded and the shear rate was decreased to 511 s^{-1} (300 rpm). The new shear stress was recorded after a period of 20 s and the shear rate was decreased to 340 s^{-1} (200 rpm). This stepwise procedure was repeated at 20 s increments for decreasing shear rates of 170, 10.2, and 5.1 s^{-1}. The method is described by Smith (5).

The time-dependent properties of selected grouts were investigated by measuring shear stress after increasingly longer rest periods. Freshly mixed samples were firstly sheared at a rate of 511 s^{-1} for 30 s. The peak and 30-s shear stress were recorded and shearing was stopped. The grout was rested for 1 min and shear stress was measured again. The experiment was repeated with the rest period being doubled each time up to a rest period of 32 min.

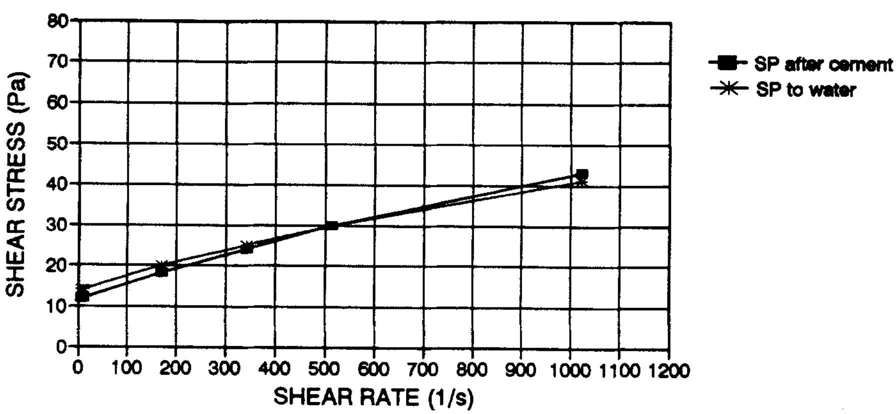

FIG. 2.
Shear stress vs. shear rate for SBR-modified Mix C, p/cm = 0.05, w/cm = 0.45.

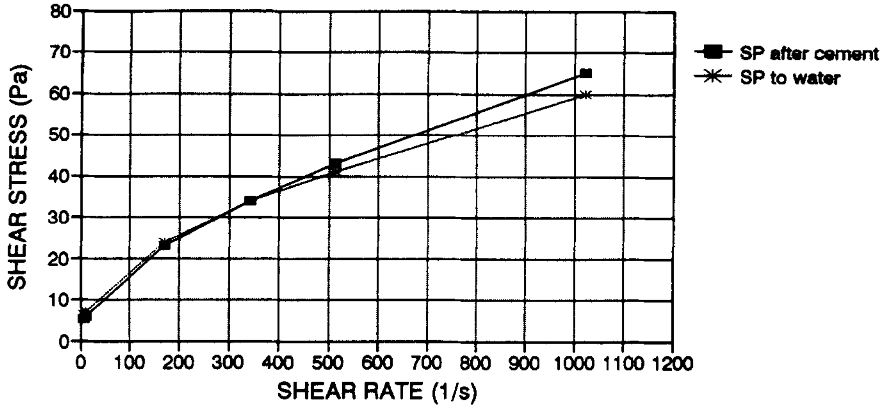

FIG. 3.
Shear stress vs. shear rate for SBR-modified Mix C, p/cm = 0.15, w/cm = 0.45.

Results

Shear stress-shear rate curves for the unmodified and latex-modified grouts are presented in Figures 1-3 and 5-10. The mixes with 100% cement, 40% blast furnace slag/60% cement, and 40% fly ash/60% cement are denoted in the figures as *C*, *BFS*, and *FA*, respectively. Styrene-butadiene and acrylic latexes are denoted was *SBR* and *ACR*, respectively. The effect of latex content and order of superplasticizer (SP) addition are shown. The figures also show the effect of slag and fly ash on the rheological behaviour of the grouts. Figure 4, is a plot of apparent viscosity vs. shear rate for the same mix as shown in Figure 3. Figure 9 depicts the effect of w/cm on an acrylic-modified grout with p/cm = 0.05. The influence of superplasticizer on grout rheology for an acrylic-modified grout with w/cm = 0.60 and p/cm = 0.15 is shown in Figure 10. Figures 11 and 12 compare the rheology for the two different latexes when added to 40% fly ash mixes with w/cm = 0.60.

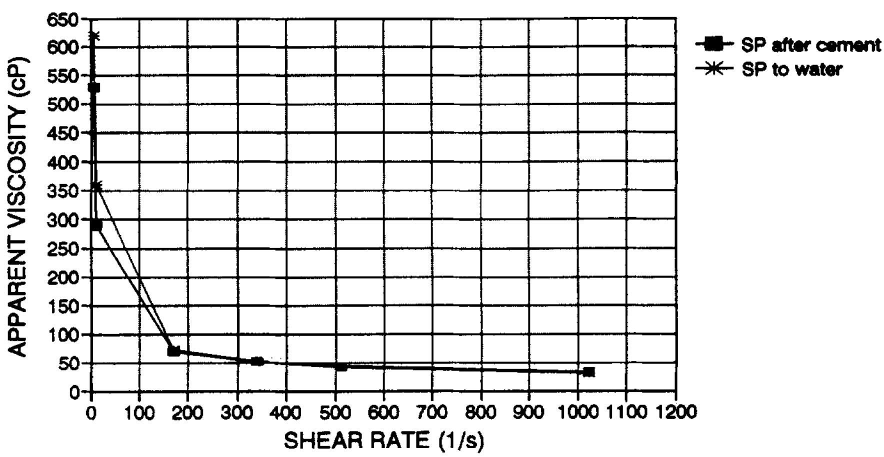

FIG. 4.
Apparent viscosity vs. shear rate for SBR-modified Mix C, p/cm = 0.15, w/cm = 0.45.

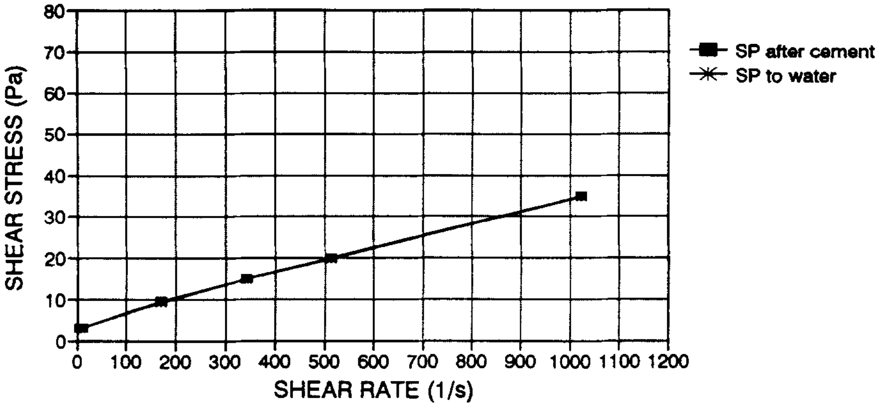

FIG. 5.
Shear stress vs. shear rate for SBR-modified Mix BFS, p/cm = 0.05, w/cm = 0.45.

The results of the time-dependent studies on unmodified Type I cement grout and styrene-butadiene-modified Type I cement grout with p/cm = 0.15 are compared in Figure 13. Both grouts had a w/cm = 0.40 and superplasticizer was added to the mixing water. The peak and 30-s apparent viscosities at 511 s^{-1} are shown for the progressive rest periods.

Discussion

The unmodified grouts with superplasticizer added after cement (Figure 1) exhibit a linear shear stress-shear rate relationship indicative of Newtonian-type behaviour. Similarly, the 100% cement and 40%BFS/60% cement grouts retain reasonably linear behaviour when superplasticizer is added to the mixing water. The grout containing fly ash with superplasticizer added to mixing water displayed curvature in the shear stress-shear rate relationship at shear rates below 170 s^{-1}.

Comparison between the curves in Figure 1 shows that adding the superplasticizer after

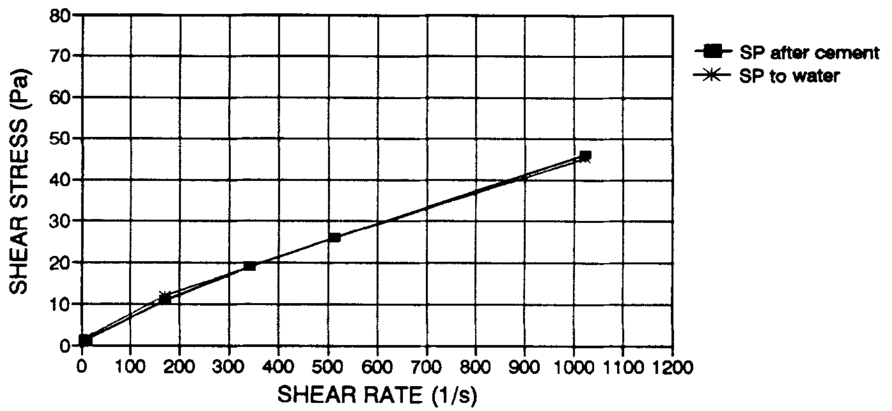

FIG. 6.
Shear stress vs. shear rate for SBR-modified Mix BFS, p/cm = 0.15, w/cm = 0.45.

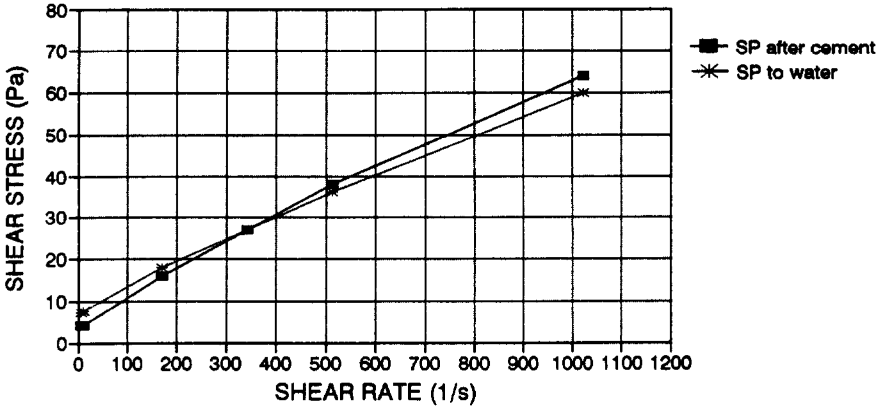

FIG. 7.
Shear stress vs. shear rate for SBR-modified Mix FA, p/cm = 0.05, w/cm = 0.45.

cement decreased the shear stress at any given shear rate. The effect of order of superplasticizer addition is not as great as that observed for grouts with a lower w/cm of 0.40 (6). Delayed addition of superplasticizer changes the adsorption behaviour and zeta potential. This is discussed further elsewhere (7,8).

Figures 2 and 3 show the effect of styrene-butadiene latex on rheology for the 100% cement grout with w/cm = 0.45. The yield stress and the shear stress at any given shear rate are increased by the addition of latex for the conditions and mix proportions studied and this can be attributed to increased interparticle attraction. The yield stress when p/cm = 0.15 is less than the value when p/cm = 0.05. This may be related to the different order of latex addition for the two mixes, as well as the change in p/cm. In the case when latex is added after cement (i.e., for p/cm = 0.05), some hydration has already occurred prior to adsorption of latex on cement particles. The penetrability of grout into voids or fissures will partially depend on the yield value. Therefore, the influence of latex on yield stress is an important consideration when using these grouts.

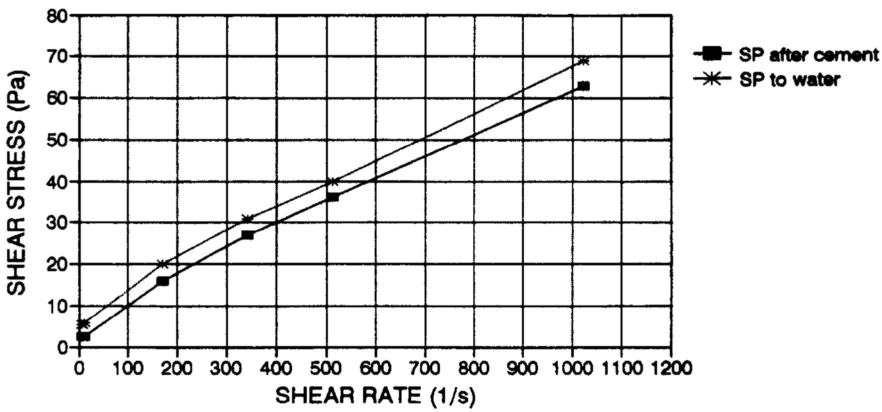

FIG. 8.
Shear stress vs. shear rate for SBR-modified Mix FA, p/cm = 0.15, w/cm = 0.45.

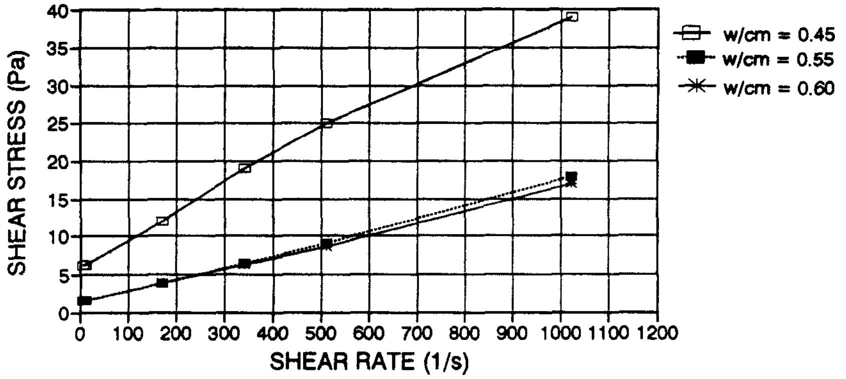

FIG. 9.
Effect of w/cm on shear stress vs. shear rate for ACR-modified Mix FA, p/cm = 0.05.

The deviation from Newtonian behaviour as styrene-butadiene latex content increases is observed in Figures 2 and 3. The grout with p/cm = 0.15 displays nonlinear pseudoplastic characteristics and has higher apparent viscosity than the mix with p/cm = 0.05 at shear rates equal to or above 170 s^{-1}. The order of superplasticizer addition has a slight effect on the shear stress-shear rate curve. The latex-modified grouts show a crossover in the curves with change in superplasticizer mixing procedure. This differs from the unmodified grouts, which have consistently lower shear stress at any shear rate when superplasticizer is added after cement. The latex will compete with the superplasticizer for adsorption on hydrating phases with resultant changes in rheological behaviour. This has been discussed in relation to slump tests on pastes containing latexes and superplasticizers (9). The shear thinning behaviour of the grout with p/cm = 0.15, particularly at low shear rates, is evident in Figure 4.

The effect of styrene-butadiene latex on the rheological behaviour of grouts containing blast furnace slag depicted in Figures 5 and 6 is less pronounced than that for grouts without slag. Compared with the 100% cement grouts in Figures 2 and 3, the latex-modified grouts containing slag are less viscous. This is in contrast to the behaviour exhibited by the same

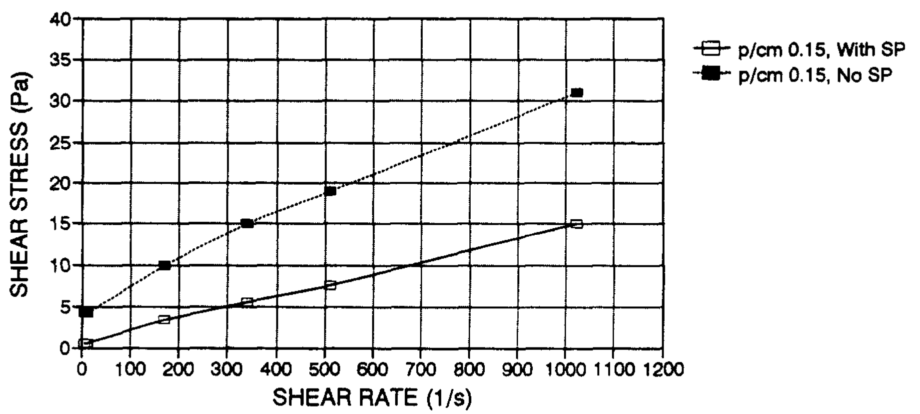

FIG. 10.
Effect of SP on shear stress vs. shear rate for ACR-modified Mix C, w/cm = 0.6.

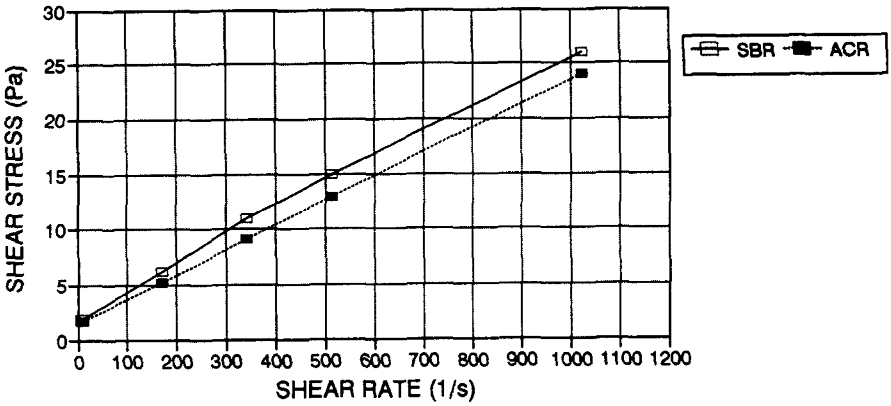

FIG. 11.
Effect of latex type on shear stress verus shear rate for Mix FA, p/cm = 0.05, w/cm = 0.6.

grouts without latex as shown in Figure 1. Therefore, the influence of latex on rheology decreases when cement is partially replaced with slag. The yield stress is decreased and apparent viscosity is increased as p/cm changes from 0.05 to 0.15. The order of superplasticizer addition has a negligible influence for the slag-modified mixes under the conditions studied.

The addition of styrene butadiene latex to grouts containing fly ash resulted in an increase in yield stress as shown by comparing Figures 7 and 8 with Figure 1. As was the case for slag-modified grouts, the effect of latex on the rheology of fly ash-modified grouts is not as great as that for 100% cement grouts. Apparent viscosity at the highest shear rate is decreased by the addition of latex. A crossover in the curves occurs for the fly ash mix with p/cm = 0.05 when the order of superplasticizer addition changes. In contrast, the fly ash grout with p/cm = 0.15 has consistently lower shear stress at any shear rate when superplasticizer is added after cement.

Increasing w/cm has the expected effect of decreasing apparent viscosity at any shear rate and decreasing yield stress of latex-modified grouts as indicated in Figure 9. Also, the grouts

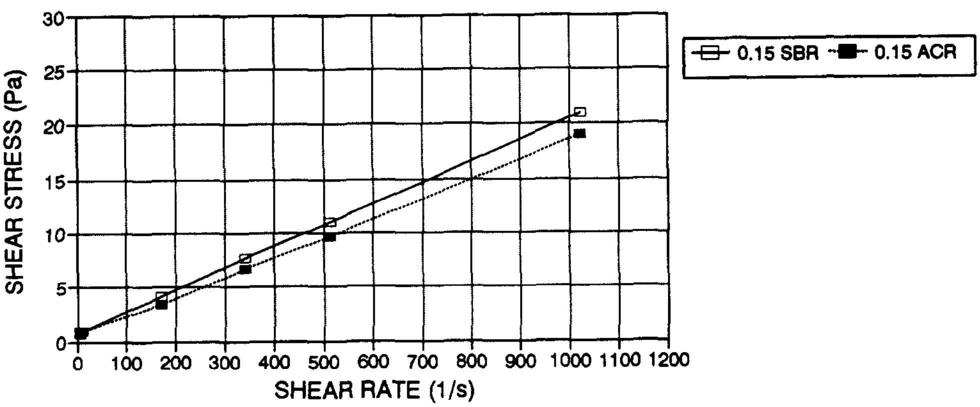

FIG. 12.
Effect of latex type on shear stress vs. shear rate for Mix FA, p/cm = 0.15, w/cm = 0.6.

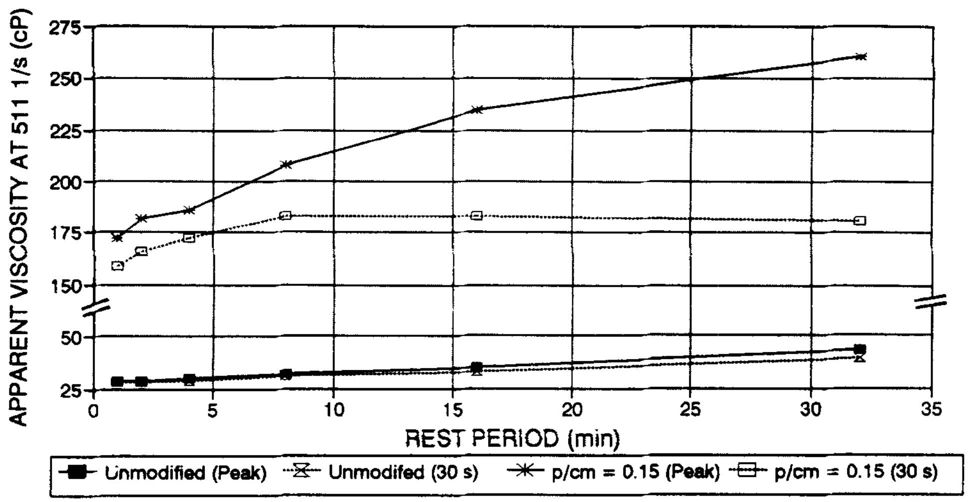

FIG. 13.
Apparent viscosity vs. rest period of unmodified and SBR-modified Mix C, w/cm = 0.45.

with higher w/cm approach Newtonian behaviour. Figure 10 shows that the addition of superplasticizer has a strong influence on the rheology of an acrylic latex-modified grout even at a relatively high w/cm of 0.60. Thus, superplasticizer can be used to advantage to reduce viscosity and yield stress where applications call for a high-fluidity grout.

The type of latex has an effect on grout rheology as shown in Figures 11 and 12 for a fly ash-modified grout with w/cm = 0.60. The grout containing styrene-butadiene exhibits greater shear stresses over the range of shear rates studied. At p/cm = 0.05 the acrylic-modified grout approaches Newtonian behaviour. Both grouts with p/cm = 0.15 have an almost linear shear stress-shear rate relationship.

The time-dependent nature of grout modified with styrene-butadiene is evident in Figure 13. For the unmodified grout, the peak apparent viscosity is slightly higher than the value at 30 s and the difference between the two increases with rest period. A linear increase in apparent viscosity with rest period occurs. When latex is added to the grout at p/cm = 0.15, significant increases in the peak and 30 s apparent viscosities result. The 30-s apparent viscosity shows an initial increase with rest period followed by almost constant values after 8, 16, and 32 min of rest. Conversely, the peak apparent viscosity continues to increase with rest period. The existence of a peak stress greater than an equilibrium stress is indicative of thixotropic behaviour. The increase in peak stress with time is due to structure formation and this is clearly more pronounced for the latex-modified grout. Thixotropy can be used to advantage, for example, where resistance to washout is required.

The above results permit comparison of the rheological behaviour of different grout formulations under laboratory conditions. It can be expected that the behaviour will differ for full-scale mixing and type of grout mixing equipment. Other factors controlling grout rheology include shear history, shear rate, time, and temperature. Hence, the flow properties need to be determined for realistic field mixing and pumping conditions and this will enable evaluation of suitability and fine tuning of mix proportions for a given application. The bleed reduction imparted by the addition of latex obviates the need to add bentonite to grout mixes. This is advantageous and simplifies the grout mixing procedure. Stability under pressure of latex-modified grouts is another important property requiring consideration when using these materials, in addition to hardened properties such as strength, ductility, adhesion to surfaces, durability, and permeability.

Conclusions

The addition of latex to cementitious grouts modifies the rheological properties. The yield stress and apparent viscosity are increased. Latex-modified grouts with relatively low water/cement ratios are shear thinning and deviation from Newtonian behaviour increases as latex content is increased. At higher water/cement ratios, the grouts tend to behave more like Newtonian fluids. Superplasticizer can be used to decrease both yield stress and apparent viscosity of latex-modified grouts. The order of superplasticizer addition generally has a small influence on rheology for the mixes and conditions studied. Latex has a less pronounced effect on grout rheology when fly ash or blast furnace slag are incorporated in the mix.

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