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Publisher's version / Version de l'éditeur:

ACI SP, pp. 221-242, 1989

National Research Council Canada

Conseil national de recherches Canada

Institute for Research in Construction

Institut de recherche en construction

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by J.J. Beaudoin and V.S. Ramachandran

Reprinted from
CANMET/ACI "Superplasticizers and Other Chemical Admixtures in Concrete"
Proceedings Third International Conference 1989
Ottawa, Canada
ACI SP 119-12, p. 221-242
(IRC Paper No. 1634)

NRCC 31109

Canada

RÉSUMÉ

On a mené une étude en vue de déterminer l'intérêt d'ajouter des polymères à la pâte de ciment, au mortier et au béton superplastifiés. Trois superplastifiants -- une mélamine-formaldéhyde sulfonée, une naphtalène-formaldéhyde sulfonée et un superplastifiant commercial -- ont été utilisés en combinaison avec des polymères expérimentaux. Les dosages de polymères et de superplastifiants variaient entre 0 et 15 % et 0 et 0,3 % respectivement.

On a déterminé l'effet des systèmes à adjuvant binaire (superplastifiant et polymère) sur les caractéristi [illegible] caractéristiques étudiées é[illegible] emps de prise, résistanc[illegible] et densité. La compatib[illegible] int de vue de l'influen[illegible] stèmes. On a observé l[illegible] inés en détail.

SP 119-12

Effect of Water Dispersible Polymers on The Properties of Superplasticized Cement Paste, Mortar, and Concrete

by J.J. Beaudoin and V.S. Ramachandran

Synopsis: A study was designed to assess the merits of polymer addition to superplasticized cement paste, mortar and concrete. Three superplasticizers - a sulfonated melamine formaldehyde, a sulfonated naphthalene formaldehyde and a commercial superplasticizer were used in combination with experimental polymers. Polymer and super-plasticizer dosages ranged from 0-15% and 0-0.3% respectively.

The effect of binary admixture systems - (superplasticizer and polymer) - on the physico-mechanical properties of the cementitious systems was determined. Properties investigated included the following: slump, slump retention, setting time, compressive strength, flexural strength, surface area, porosity and density. Compatibility of the polymers with the superplasticizer was assessed with respect to the influence of the individual admixtures on the properties of the various systems. Synergistic effects were observed for one polymer, the results of which are discussed in detail.

Keywords: cement pastes; compressive strength; concretes; ethylene copolymers; flexural strength; mortars (material); plasticizers; plastics, polymers, and resins; porosity; setting (hardening); shrinkage; styrene copolymers; workability

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INTRODUCTION

Superplasticizing admixtures are widely used in concrete technology to obtain concrete having high workability or high strength. Superplasticizers are used in combination with other admixtures to obtain additional beneficial effects such as better durability, acceleration and retardation. Polymer additives such as latexes, powdered emulsions and water soluble polymers are used in mortar and concrete to control chemical resistance and drying shrinkage, increase tensile strength and improve bonding characteristics. It can be foreseen therefore that the binary admixture containing superplasticizer and polymer may result in certain beneficial effects to concrete that cannot be derived by using them individually. There is a paucity of data on properties of paste, mortar and concrete containing both super-plasticizers and water dispersible polymers [1]. This paper deals with the effect of two water dispersible polymers used in combination with three superplasticizers on the physico-mechanical properties of cement paste, mortar and concrete.

EXPERIMENTAL

Materials

Portland Cement: The composition was as follows: SiO_2 = 22.00%; Al_2O_3 = 4.88%; Fe_2O_3 = 1.93%; CaO = 63.29%; MgO = 4.24%; SO_3 = 1.95%; Na_2O = 0.17%; K_2O = 0.78%; TiO_2 = 0.20%; P_2O_5 = 0.11%; Mn_2O_3 = 0.02%; SrO = 0.05%. Ignition loss = 0.70%; Blaine surface area = 351 m^2/kg.
Superplasticizer: Two types of superplasticizers were used, sulfonated melamine formaldehyde type (SMF) and sulfonated naphthalene formaldehyde type (SNF). In addition an SNF based commercial superplasticizer (CSP) designed to minimize slump loss was used. Superplasticizer was used in amounts up to 0.3% by weight of cement.
Polymer: Two water dispersible polymers were used either alone or in combination with superplasticizer. They were styrene butadiene copolymer (SBR) supplied by Dow Chemical USA and ethylene vinylacetate copolymer (EVA) supplied by Nihon Kasei Co., Japan. The polymers were used in amounts from 0-15% by weight of cement.

Fine Aggregate: Natural sand having a fineness modulus of 2.41 was used.
Coarse Aggregate: Graded crushed aggregate comprised limestone in the particle size ranges 9.5 to 6.4:12.7 to 9.5:19.1 to 12.7 mm in the following proportion by weight; 1:1.5:2.75.

Mix Preparation

Cement Paste: Cement pastes containing superplasticizer (0-0.3%) and water - soluble polymer (0-15%) were prepared at three water-cement ratios, w/c = 0.32, 0.45 and 0.52. Cement paste specimens were cured in two ways. One set was cured continuously at 100% RH, and the other, initially for 1 day at 100% RH followed by continuous curing at 50% RH.
Mortar: Mortar mixes containing superplasticizer (0-0.3%) and 2% water-soluble polymer were prepared at a nominal water-cement ratio = 0.50. Mix proportion of cement:natural sand = 1:2.75.
Concrete: Concrete mixes containing superplasticizer (0-0.3%) and water-soluble polymer (0-15%) were prepared at a nominal water-cement ratio = 0.50. The mix proportion of concrete was cement:sand:coarse aggregate = 1:2:3.2. Some mixes were made with water-cement ratios of 0.35 and 0.40.

Fresh Properties:

Cement Paste: Mini-slump tests for cement paste were carried out according to procedure described by Kantro [3]. Samples were re-used in establishing slump loss - time curves. The sample was carefully sealed in a container during test intervals and mixed for 1 minute prior to subsequent test.
Mortar: Mini-slump tests for mortar were carried out with a slump cone having the following dimensions: top diameter 37.5 mm, bottom diameter 75.0 mm and height 112.5 mm. The mixing and testing were conducted in accordance with ASTM C305.
Concrete: The method for measuring slump of concrete conformed to ASTM C192-81 and ASTM C143-78. A .046 cubic meter pan mixer was used for all concrete mixes. Slump areas were obtained by using average of 3 values for the diameter.

Physical Properties:

Cement Paste: Density was determined using solid volume measurements obtained with a helium pycnometer. Porosity was also determined using helium pycnometric methods. Nitrogen surface area measurements were carried out with a Quantasorb surface area analyzer. Shrinkage measurements were made with a modified Tuckerman optical extensometer having a sensitivity of 4 microstrain. Shrinkage was measured on prism specimens 10 x 25 x 1 mm thick moist cured for 1 d and conditioned at 57% RH for 28 d followed by exposure to 11% RH for 14 d. Shrinkage measurements on some specimens were made between 57 and 11% RH. Initial and final setting times were obtained according to procedures described in ASTM C191.
Concrete: The initial and final setting times were obtained using ASTM C403-85.

Mechanical Properties:

Cement Paste: Flexural strength of cement paste disc specimens 25.4 mm Ø x 1.27 mm Ø (1" x .050 in. thick) was calculated by using an expression for the maximum tensile stress developed at the center of a centrally loaded simply supported circular plate [2]. For each determination flexural strength was calculated as the average value for three test specimens. Load was applied using an Instron testing machine. Loading rate (cross-head speed) was 5×10^{-4} cm/min.

Compression tests on 5.1 cm cubes of cement paste were carried out on a Tinius Olsen testing machine using a loading rate equivalent of 0.20 MPa s^{-1}. Three specimens were tested for each test condition at 1, 3, 7 and 28 days.
Mortar: Compression tests on 5.1 cm mortar cubes (3 for each test condition) were carried out using a Tinius Olsen testing machine at a loading rate of 0.20 MPa s^{-1}. Test ages were 3, 7 and 28 days. Tests were performed according to ASTM C109.
Concrete: Compression tests on 15.2 x 30.5 cm concrete cylinders were carried out at 3, 7 and 28 days. Flexural strength tests utilized 7.6 x 7.6 x 30.5 cm concrete beams. Tests were performed in accordance with ASTM C39 and C78. Three specimens for each test condition were tested for both compression and flexural strength determinations.

RESULTS AND DISCUSSION

CEMENT PASTE

Slump

The effect of SBR polymer in combination with SMF superplasticizer on the initial and 3 h minislump can be assessed from figures 1 and 2. In figure 1 the minislump values for cement pastes (w/c = 0.45 and 0.52) containing no admixtures, 0.3% SMF, 2% SBR polymer and 0.3% SMF + 2% SBR combination are plotted. The reference cement paste (w/c = 0.45) has the lowest initial slump and at 3 h it has practically the same value. Addition of SBR increases the initial slump slightly and at 3 h it has a similar value to that of the reference. Addition of SMF increases the initial slump significantly, the value being about 4.5 times higher than that of the reference paste. Within 1 h the slump value decreases by about 40% and in 3 h by more than 50%. At 3 h the value is considerably higher than that of the reference. The SMF + SBR combination increases the initial slump to the greatest extent, the value being as high as 385 cm^2. Addition of SBR to SMF is not only compatible but has a synergistic effect. The slump decreased by about 50% in 1 h. At 3 h the slump is 118 cm^2. At 3 h the slump values for paste containing SMF + SBR and SMF (w/c = 0.45) are similar indicating that the effect of SBR on slump retention at 3 h is minimal.

The initial slump value of the reference cement paste (w/c = 0.52) is 95 cm^2 compared to a value of 56 cm^2 for that prepared at a w/c = 0.45. The initial slump values for the paste containing SMF and SMF + SBR are 275 and 358 cm^2 respectively. The corresponding values at w/c = 0.45 are 250 and 385 cm^2. These results suggest that the initial slump values for most samples, as expected, are higher at a w/c = 0.52 than at w/c = 0.45 [6].

The final slump values at 3 h for the reference, SBR, SMF and SMF + SBR (w/c = 0.52) are respectively 80, 124, 162 and 236 cm^2. The combination of SMF and SBR shows the best slump retention characteristics. Slump retention at w/c = 0.52 is significantly better than that at w/c = 0.45. At a higher w/c the mean particle distance is increased and the tendency for agglomeration of particles due to physical and chemical interactions is reduced. The addition of SBR enhances not only the initial slump of the paste containing SMF but also the slump retention characteristics. In terms of workability addition of SBR is compatible with pastes containing SMF; in fact workability is improved.

The increase in the initial slump of pastes containing SMF + SBR may be explained as follows. The slump of cement paste is determined by the C_3A + Gypsum reaction and also the dispersibility of the C_3S phase. Dispersibility of C_3S depends on the amount of SMF available for adsorption on the hydrating C_3S. When SMF + SBR are added together, SBR competes with SMF for adsorption on the C_3A + Gypsum mixture. Consequently more SMF will be available for dispersion of the C_3S phase. The dominant phase that influences the slump in cement paste has been shown to be the C_3S phase [4].

The effect of different amounts of SBR on the slump characteristics of cement paste containing 0.3% SMF is given in figure 2. The initial slump decreases as the amount of SBR increases, the values being 385, 358, 306 and 274 at 2%, 5%, 10% and 15% SBR respectively. The initial slump of superplasticized cement paste without SBR is 250 cm^2. Thus addition of SBR increases the slump of super-plasticized cement paste at all dosages. Slump values at 3 h increase as the dosages of the added SBR is increased; the slump values with 0, 2, 5, 10 and 15% SBR are 114, 118, 130, 185 and 215 cm^2 respectively. One possible explanation is that as the dosage of SBR is increased its interaction with C_3A and C_3S increases. The effectiveness of the dispersion of C_3S by SMF is thus increased.

The effect of SBR and EVA polymers in combination with both SMF and SNF on initial and 3 h minislump can be determined from figures 3 and 4. Minislump results are presented in figure 3 for cement paste (w/c = 0.32) containing no admixtures, 0.3% SMF and SNF, 10% SBR and EVA polymer and combinations of 0.3% superplasticizer and 10% polymer. The initial slump of all the paste mixes increases with respect to the reference with the exception of the 0.3% SNF + 10% EVA combination. The initial slump of the paste containing 0.3% SMF alone is greater than that containing 0.3% SNF by 20 cm^2. Mixes containing polymer alone also have a greater initial slump than the reference with the slump of SBR pastes exceeding that of EVA pastes by about 15 cm^2. Addition of 10% SBR and EVA with 0.3% SNF results in a decrease in the initial slump values relative to the addition of SNF alone. The initial slump of the reference paste is not affected with the combination 0.3% SNF + 10% EVA. Slump retention at 3 h with the combination 0.3% SMF + 10% SBR is better than all other combinations. The combination 0.3% SNF + 10% SBR shows some slump retention at 3 h.

Minislump results for cement paste (w/c = 0.52) containing 0.3% SMF and SNF and 10% SBR are presented in figure 4. The initial and final slumps are greater than those for pastes at w/c = 0.32. Addition of 10% SBR to SNF does not improve either the initial or final slump values. The initial slump and slump retention is significantly improved with the combination of 0.3% SMF + 10% SBR.

Compressive Strength

The influence of SMF, SBR and their combination on compressive strength development of paste cured at 50% RH is shown in figure 5. The reference paste and two pastes one containing 0.3% SMF and the other 2% SBR, at 1 day shows strength values of 14, 20.6 and 15.3 MPa respectively and at 28 d the corresponding values are 42.8, 45.9 and 42.9 MPa. A comparison of the strength values of these three pastes shows that the strength values are higher for the paste containing SMF. The paste with SBR exhibits similar strengths to those of the reference. The combination, SMF + SBR, shows higher strength than either SMF or SBR; at 28 days the value is 24% higher than the reference. With higher amounts of SBR eg. 15% the strength is decreased drastically at 1 day and 28 days, the 28 day value being 28.1 MPa compared to 42.8 MPa for the reference. The compressive strength of the mix containing 0.3% SMF + 15% SBR is similar to that containing 15% SBR. Thus compressive strength development in the presence of SMF is not affected by SBR addition.

All samples cured at 100% RH show higher strengths than those cured at 50% RH. At 28 days of curing pastes containing the reference, SMF, SBR and SMF + SBR combination show strengths of 59.2, 58.5, 53.7 and 57.1 MPa respectively. The corresponding values for those cured at 50% RH are 42.8, 45.9, 42.9 and 53.1 MPa respectively. The higher strength development in pastes cured at 100% RH may be attributable to the higher degree of hydration. The results indicate that addition of SMF compensates for the slight decrease in strength caused by the addition of SBR.

Even at 50% RH however, at 28 days, addition of the SMF + SBR combination gives higher strength than the reference and those with SMF or SBR. Addition of 2% SBR to 0.3% SMF does not interfere with strength development. At higher amounts of SBR eg. 15%, the strength at 28 days is drastically reduced to 28.1 MPa compared to 42.8 MPa for the reference. Addition of 0.3% SMF however, slightly increases the strength viz from 28.1 MPa to 30.0 MPa. The strength reduction caused by higher amount of SBR may be explained by its lower modulus of elasticity and lower density compared to the cement paste matrix [5]. If larger amounts of SBR are to be used in combination with SMF, the strengths can be recovered by using lower amounts of Water and higher cement contents.

The solid densities of the reference, that containing 0.3% SMF and 15% SBR were found to be 2,32, 2.38 and 2.14 respectively. Porosity measurements were carried out to determine if the low strengths in samples containing higher amounts of SBR could be explained by differences in porosity values. The porosity of the reference sample and that containing 15% SBR is 35.3 and 34.6% respectively. The lower than expected porosity of the paste containing 15% SBR may be due to the blockage of pores by the polymer. It appears that true porosity in the cement-polymer system cannot be determined accurately.

Use of SMF with SBR is compatible from the strength development point of view because some strength losses caused by higher amounts of SBR are partially recovered by the addition of SMF.

<u>Flexural Strength</u>

Flexural strengths of cement pastes containing SMF and SMF + SBR and cured for 1, 3, 7 and 28 days at 50% RH or in water were determined. Samples cured continuously at 100% RH generally exhibited higher strengths than those cured at 50% RH. For example at 28 days, additions of 2% SBR and 0.3% SMF + 2% SBR resulted in a flexural strength of 7.83 MPa and 8.42 MPa respectively at 50% RH; the corresponding values for samples cured at 100% RH were 10.9 MPa and 11.6 MPa. The greater rate of hydration can explain the higher strengths developed at 100% RH.

At 1 day the SMF + SBR combination gave a value intermediate between that for SBR or SMF but it was higher than that of the reference. The strengths increase with the age of curing. The highest strength was exhibited in the presence of 0.3% SMF + 15% SBR the value being 9.87 MPa compared with 7.70 MPa for the reference. Addition of a polymer is known to increase the long term flexural strength of cement paste and concrete. The presence of SMF only marginally affected the flexural strength increase developed by SBR. The enhanced flexural strength in the presence of SBR is explained by effects such as film formation and filling of cracks [6].

<u>Shrinkage</u>

In general the shrinkage from 100-57% RH is higher than that occurring between 57% RH and 11% RH (Table I). The higher shrinkage with the SMF or SBR could be attributed to the greater dispersive effect and larger surface areas that result from the dispersion. Larger surface areas generally increase shrinkage [7].

Addition of the combination SBR + SMF in fact results in lesser shrinkage compared either to SMF or SBR alone or to that of the reference. The explanation is not immediately evident and one of the possibilities is that the interaction of SMF with SBR may somehow inhibit the transfer of water from the system.

Shrinkage from 57 - 11% RH involves effects due to water removal from capillaries and interlayer regions. Major consolidation effects have already taken place in this RH region. However it is known that from 11 - 0% RH length change is caused by removal of interlayer water which results in much larger shrinkage [8]. At higher polymer contents the film formation effect may reduce water ingress into interlayer positions thus decreasing the potential for shrinkage.

<u>Setting</u>

All admixtures retard both the initial and final setting times of cement paste compared to that without admixtures. Although SBR or SMF added separately retard the setting times by 40 - 60 mins. (initial setting time) and 30 - 50 mins. (final setting time) the combination seems to retard further the setting times (Table II).

MORTAR

<u>Slump</u>

The effect of SBR and EVA polymer in combination with SMF on the initial and two hour minislump can be assessed from figure 6. The combination 0.3% SMF + 2% SBR shows greater slump retention than other mortars. Some measurements were carried out to determine if the initial slump and final slump values at 2 hours could be explained by differences in air contents. The values for the reference, 0.3% SMF, 0.3% SMF + 2% SBR and 2% SBR mixes were 4.5, 4.3, 2.5 and 3.5% respectively. Thus the air content values had no significant effect on slump values. With 2% SBR or 2% EVA the use of SMF results in higher initial and final slumps than those for SMF alone. The trends shown for the SMF-SBR combination in mortar mixes are similar to those shown for paste mixes. Slump value at 2 h is better with polymer addition (SBR or EVA) than without it. Addition of SBR or EVA in the amount of only 2% can reduce slump loss of mortar with 0.3% SMF.

<u>Compressive Strength</u>

The effect of polymer addition on compressive strength of superplasticized mortar is shown by the data presented in Table III. The addition of 0.3% SMF increases strength at ages from 1 to 28 days for curing at 100% RH, but has no beneficial effect on strength for curing at 50% RH.

Addition of 2% SBR alone reduces compressive strength significantly at all ages; strength values of mortar containing 0.3% SMF + 2% SBR are, however, only slightly less than those of the reference. Higher amounts of SBR addition result in significantly lower strengths compared to the reference.

CONCRETE

<u>Slump</u>

The effect of different amounts of superplasticizer on slump retention of concrete containing SBR was determined. Previous work [9] had indicated that small amounts of SBR might be effective in controlling slump loss of superplasticized concrete [9].

In this study 2% SBR polymer was added to concrete containing 0.1 - 0.3% SMF and the resulting effect on slump loss with time was determined (figure 7).

Although the polymer by itself did not increase the initial slump, in combination with SMF, slump values were consistently higher at all dosages. Slump increased by about 100% for concrete containing 0.3% SMF. At 2 hours slump retention was significantly greater for concrete containing 0.2 - 0.3% SMF. Slump decreased only by about 6 cm for the (0.3% SMF + 2% SBR) concrete, whereas for 0.3% SMF concrete the corresponding value was more about 10 cm. For all dosages of SMF, addition of SBR polymer is effective in reducing slump loss.

The relative effects of the admixture formulation used in this work (SMF + SBR) and those of a commercial admixture (CSP), at two dosage levels are compared in figure 8. The initial slump increase with the commercial admixture is slightly less than that with SMF + SBR. It is also evident that the slump values at 4 h are higher with the SMF + SBR combination. Slump value with SMF + SBR at 4 h is 8 cm compared to the value of 5 cm for the commercial formulation. Use of a slightly higher dosage of the commercial admixture, i.e. 0.36% in place of 0.3%, only marginally increases slump retention. Higher dosages were not used because they resulted in unusually high setting times that are not acceptable by the ASTM or CSA standards. It may be argued that the slump retention with SMF + SBR is better because the initial slump itself is higher with this formulation and therefore retention would also be higher. The formulation (0.1% SMF + 2% SBR) in figure 7 increased the initial slump of concrete to about 20 cm and this formulation may be compared with the effect of 0.3% CSP (figure 8) which has also an initial slump of 20 cm. The slump of concrete containing 0.3% CSP (figure 8) and that containing 0.1% SMF + 2% SBR (figure 7) at 2 h is about 9 cm, demonstrating that the slump retention of these systems is comparable.

<u>Compressive Strength</u>

Compressive strength results for concrete containing 0.3% SMF and 0.3% SMF + 2% SBR are presented in figure 9. All mixes have a slump of about 12.7 cm. The strength of concrete containing 0.3% SMF + 2% SBR is greater than that containing only 0.3% SMF at all test ages. The reference has lowest strength at all ages.

Results for concrete having higher slump (20.3 cm) are given in Table IV. The compressive strength of concrete containing SMF alone is higher than the reference but the combination of 0.3% SMF and 2% SBR has lower compressive strength than concrete with SMF alone and slightly lower strength than the reference at 28 days. This indicates that increases in the compressive strength properties of concrete containing binary admixture systems are dependent on slump. Strength decreases at higher slump for concrete cured at 100% RH may result from transport of the polymer to the concrete surface through a leaching process. Care should be taken to avoid prolonged moist curing of high slump concrete containing SBR to eliminate lower strength levels.

<u>Flexural Strength</u>

Flexural strength results for concrete (12.7 cm slump) containing 0.3% SMF and 0.3% SMF + 2% SBR are reported in Table V. The trends are similar to those for compressive strength. Mixes in order of increasing strength (at all test ages) are: reference < 0.3% SMF < 0.3% SMF + 2% SBR.

<u>Modulus of Elasticity</u>

There is no significant change in the modulus of elasticity of the 12.7 cm slump concrete concrete at 28 days for all mixes. At 3 and 7 days however, the concrete with SMF or SMF + SBR shows higher modulus than the reference concrete.

Setting Time

Some experiments were carried out to determine the effect of binary admixture systems on initial and final setting times of concrete having a 9 cm slump. Tests were carried out according to ASTM C-403-85. Mixes included concrete with no admixture, 0.3% SMF + 2% SBR and combinations of 0.3% CSP and SBR.

The initial set should be at least 1 h later but should not be more than 3 h later than the reference mix to satisfy requirements for ASTM standard for type G admixtures. The final set should not be later than 3 h with respect to the reference mix. Applying these criteria admixtures 0.3% SMF + 2% SBR and 0.3% CSP are acceptable formulations. The commercial admixture formulation CSP marginally passed the initial set requirements. All other admixtures did not pass the initial set requirements. However, formulations containing 0.3% CSP and SBR pass the final set requirements but show slightly higher earlier setting times by about 15-30 mins. This could perhaps be overcome by the addition of less than 1% SBR to the formulation or adjusting the commercial polymer to a slightly lower level. In other words the addition of SBR to the commercial polymers could be adjusted so that increased slump retention can be obtained without failing the setting time requirements. One of the limiting factors in the use of retarders in formulations containing superplasticizers is that they promote excessive retardation of setting that may not conform to the standards. The commercial admixture cannot be used by itself at dosages higher than 0.3%, even though better slump retention characteristics may result.

CONCLUSIONS

Concluding statements are given separately for cement paste, mortar and concrete.

Addition of SBR and EVA copolymers to cement paste containing SMF superplasticizer increases its slump significantly. Initial and final slumps of the pastes containing binary admixtures systems are greater at higher water-cement ratios. Addition of SBR copolymer to cement paste containing SNF superplasticizer increases its slump to a lesser degree than with SMF superplasticizer. The combination of SNF and EVA has no beneficial effect. The effectiveness of SMF and SNF in combination with SBR is dependent on water-cement ratio of cement paste. At higher water-cement ratios addition of SBR to SNF has no positive effect. Slump retention increases with the amount of polymer added. Slump retention at 3 h for low water-cement ratio paste made with the SMF-SBR combination is higher than with all other combinations. The combination of the SMF-SBR admixture shows a synergistic effect with respect to the development of flexural strength and compressive strength at 28 days. The combination of SBR and SMF reduces the shrinkage of cement paste relative to that obtained with the addition of the polymer or superplasticizer alone. Setting time with the SBR-SMF combination is slightly higher than that obtained using individual admixtures. The use of the 0.3% SMF + 2% SBR admixture combination in cement paste does not affect the beneficial effects derived by either of them.

Addition of SBR or EVA copolymer is effective in controlling slump loss of mortar containing SMF. Slump-time characteristics for the SMF-SBR combination in mortar mixes are similar to those for paste mixes. Addition of 2% SBR to mortar containing SMF results in only a small reduction of compressive strength.

Addition of polymer to superplasticized concrete increases slump retention. A formulation based on the SMF-SBR binary system provides better slump retention than the commercial counterpart. The SMF-SBR formulation satisfies the setting characteristics for a type G admixture as prescribed by ASTM and CSA standards. Addition of SBR copolymer in controlled amounts to the commercial formulation tested increases the slump retention further.

A qualitative assessment of the slump retention characteristics of mortar and concrete containing a combination of superplasticizer and water dispersible polymer can be obtained from minislump tests of cement paste containing the binary admixture system.

ACKNOWLEDGEMENTS

The authors would like to thank R.E. Myers, R. Lacroix and G.M. Polomark for their assistance with the experimental work and G. Polomark for preparation of the figures.

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TABLE 1--SHRINKAGE OF CEMENT PASTES CONTAINING SUPERPLASTICIZER AND POLYMER

Material	Shrinkage, % 100 - 57% RH	57 - 11% RH
Reference	0.38	0.157
Cement + 0.3% SMF	0.57	0.125
Cement + 2% SBR	0.53	0.193
Cement + 0.3% SMF + 2% SBR	0.36	0.159
Cement + 10% SBR		0.064
Cement + 15% SBR		0.070
Cement + 0.3% SMF + 15% SBR		0.068

(Moist curing at 100% RH at higher SBR contents detrimental).

TABLE 2--SETTING TIMES OF PASTES CONTAINING SUPERPLASTICIZER AND POLYMER

	Initial Setting h : min	Final Setting h : min
1. Cement	2.00	2.35
2. Cement + SMF	2.55	3.55
3. Cement + 2% SBR	3.00	3.25
4. Cement + 5% SBR	2.40	3.05
5. Cement + SMF + 2% SBR	3.40	4.05
6. Cement + 5% SBR	3.35	3.55

TABLE 3--COMPRESSIVE STRENGTH OF MORTAR CUBES CONTAINING SBR AND SMF TYPE SUPERPLASTICIZER

	COMPRESSIVE STRENGTH (MPa)						
	Age						
	1 d	3 d		7 d		28 d	
Relative Humidity	100	100	50	100	50	100	50
Reference	14.8	34.6	35.7	46.1	41.5	56.2	45.6
0.3% SMF	18.2	37.3	36.1	48.3	42.3	57.5	42.9
2% SBR	11.5	24.4	23.0	32.3	28.6	40.4	31.8
0.3% SMF + 2% SBR	15.5	33.8	33.7	42.5	41.7	51.4	43.0
15% SBR	8.7	22.1	21.4	29.9	32.6	37.9	39.8
0.3% SMF + 15% SBR	9.3	25.5	26.9	31.0	34.8	39.8	41.9

TABLE 4--COMPRESSIVE STRENGTH OF CONCRETE CONTAINING SBR AND SMF TYPE SUPERPLASTICIZER (SLUMP = 20.3 CM): 100 PERCENT RH

Concrete	Compressive Strength (MPa)		
	3 d	7 d	28 d
Reference	15.6	20.2	27.4
0.3% SMF	23.8	26.5	31.1
0.3% SMF + 2% SBR	20.1	22.8	26.9

TABLE 5--FLEXURAL STRENGTH AND MODULUS OF ELASTICITY OF CONCRETE CONTAINING SBR AND SMF TYPE SUPERPLASTICIZER (SLUMP = 12.7 CM); 100 PERCENT RH

Concrete	Flexural Strength MPa			Modulus of Elasticity MPa x 10^{-3}		
	3 d	7 d	28 d	3 d	7 d	28 d
Reference	22.0	26.6	36.9	1.49	1.76	1.97
0.3% SMF	29.7	34.1	39.0	1.97	2.07	2.14
0.3% SMF + + 2% SBR	33.1	37.0	51.7	2.03	2.07	2.15

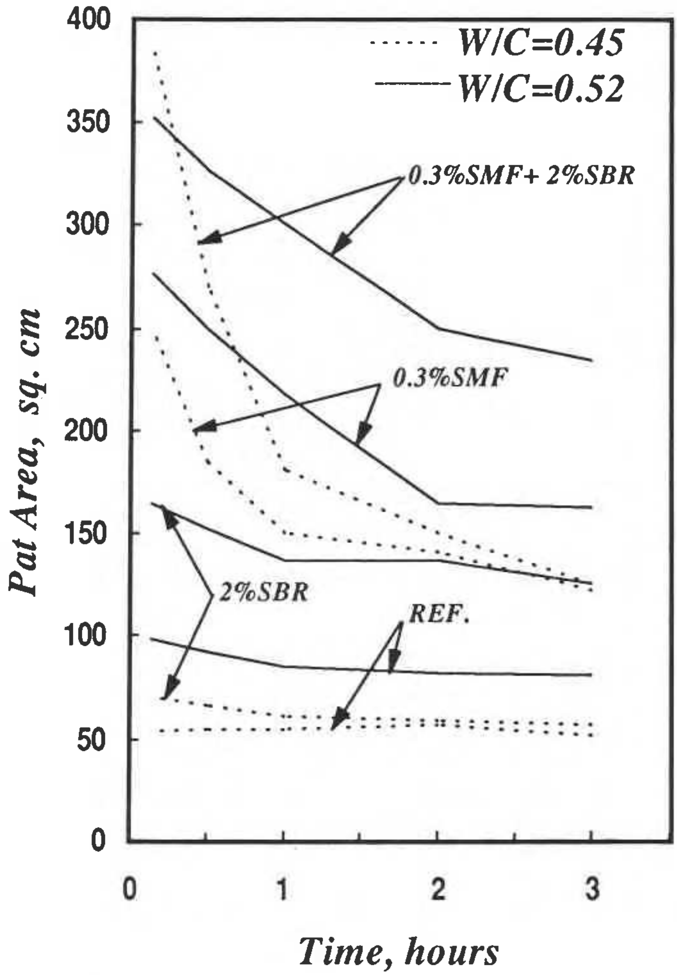

Fig. 1--Minislump of cement paste containing SBR polymer with SMF type superplasticizer

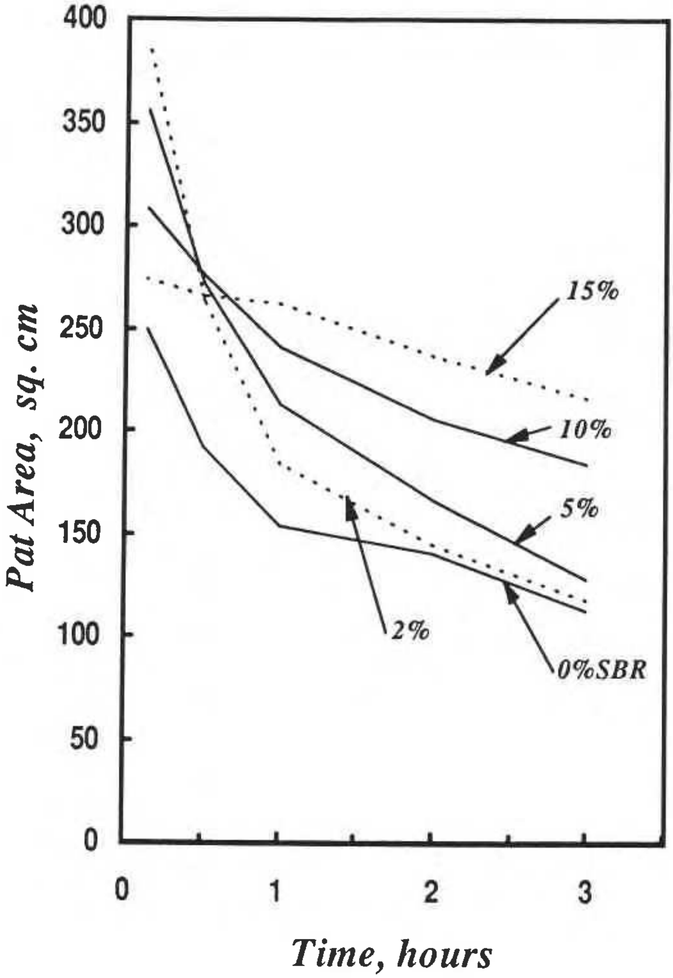

Fig. 2--Minislump of cement paste containing different amounts of SBR with 0.3 percent SMF superplasticizer (w/c = 0.45)

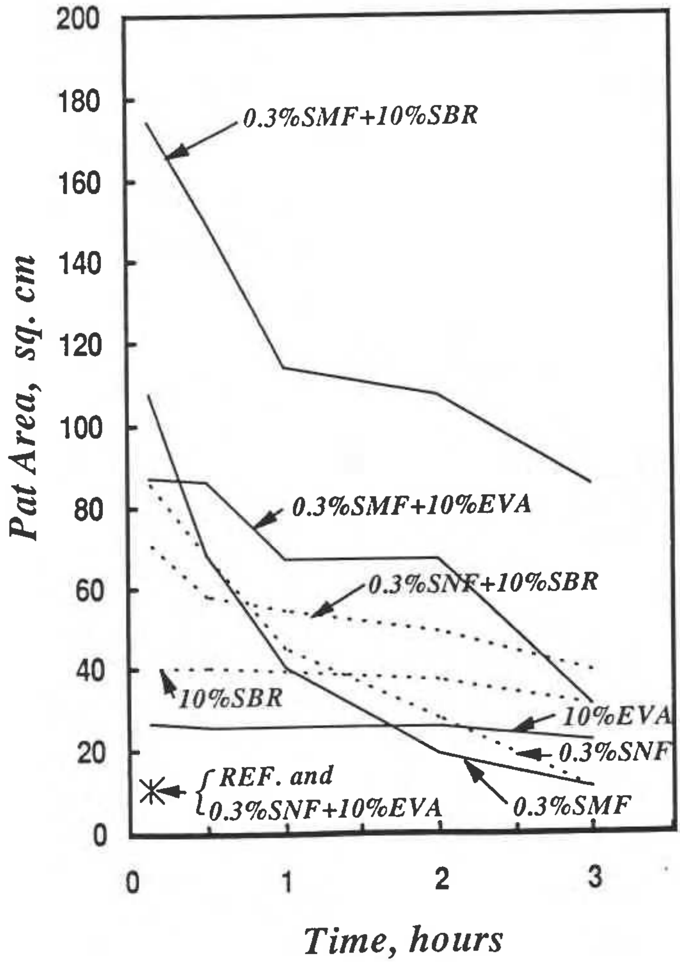

Fig. 3--Minislump of cement paste containing SBR and EVA in combination with SNF and SMF superplasticizer (w/c = 0.32)

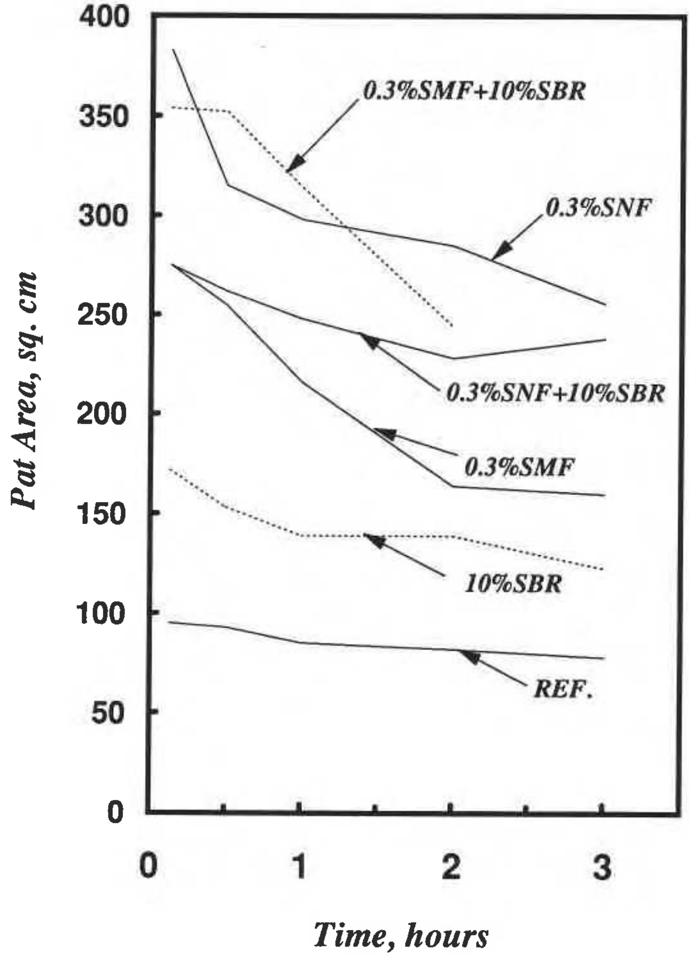

Fig. 4--Minislump of cement paste containing SBR in combination with SNF and SMF superplasticizer (w/c = 0.52)

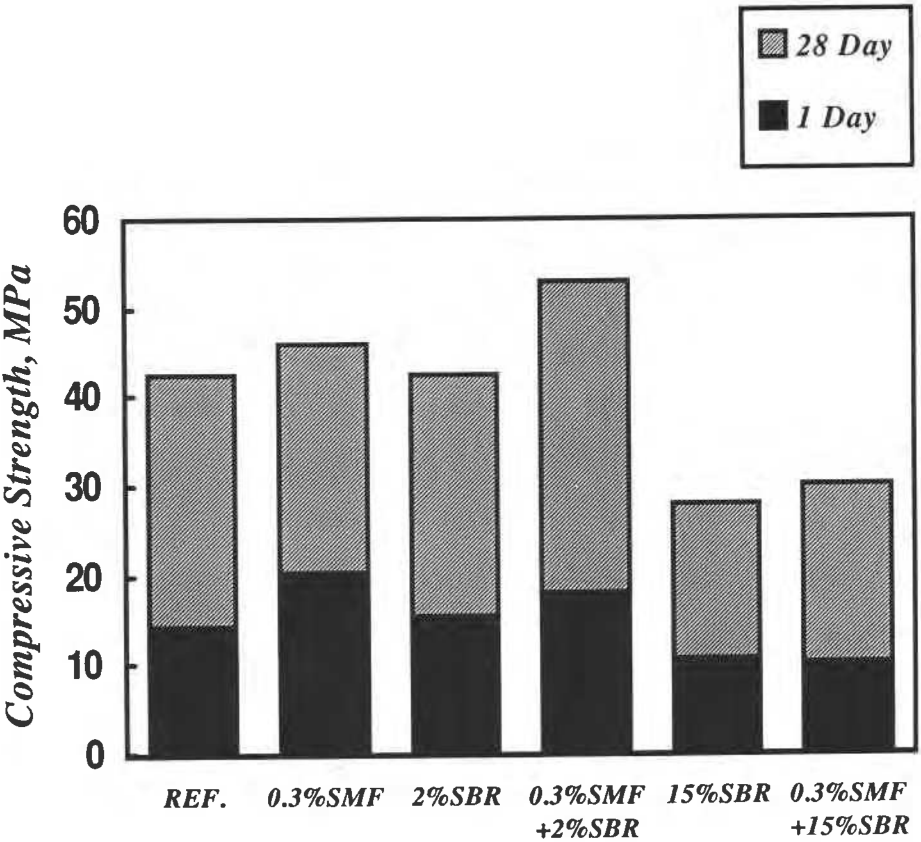

Fig. 5--Compressive strength of cement paste containing SBR polymer with SMF superplasticizer (w/c = 0.45)

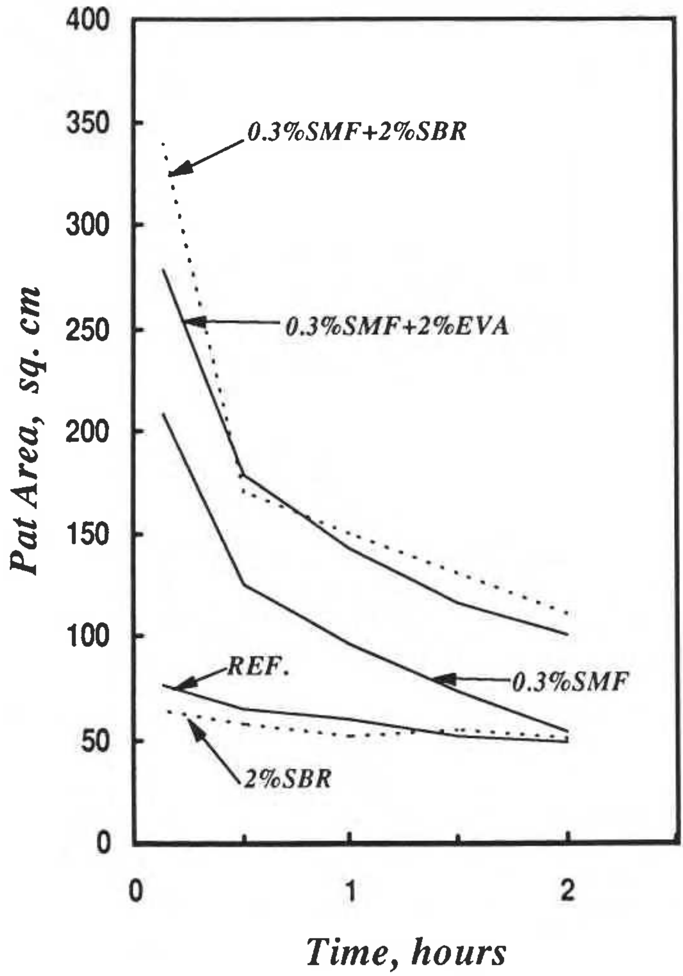

Fig. 6--Minislump of cement mortar containing SBR and EVA polymers with SMF superplasticizer (c/s = 0.36) (w/c = 0.50)

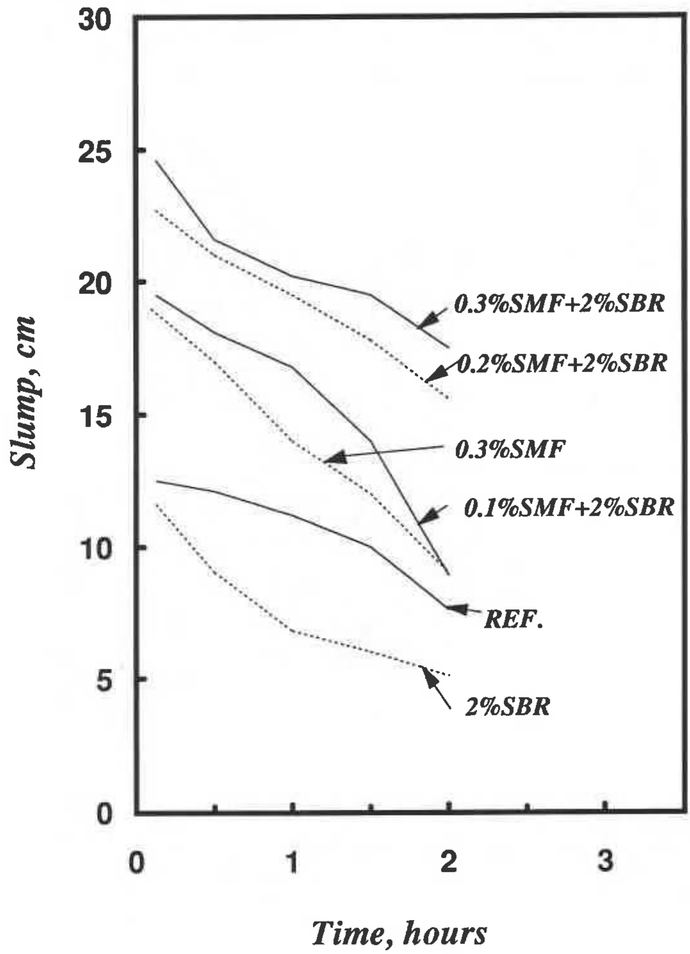

Fig. 7--Slump changes in concrete containing SBR with different amounts of SMF superplasticizer

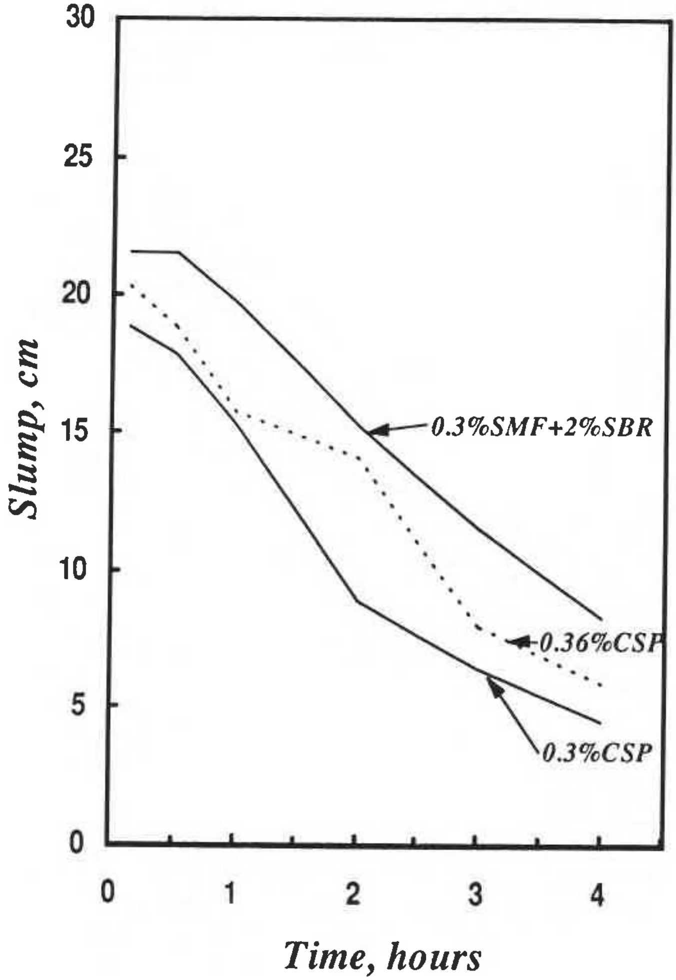

Fig. 8--Relative slump changes in concrete containing a commercial superplasticizer (CSP) and SMF + SBR

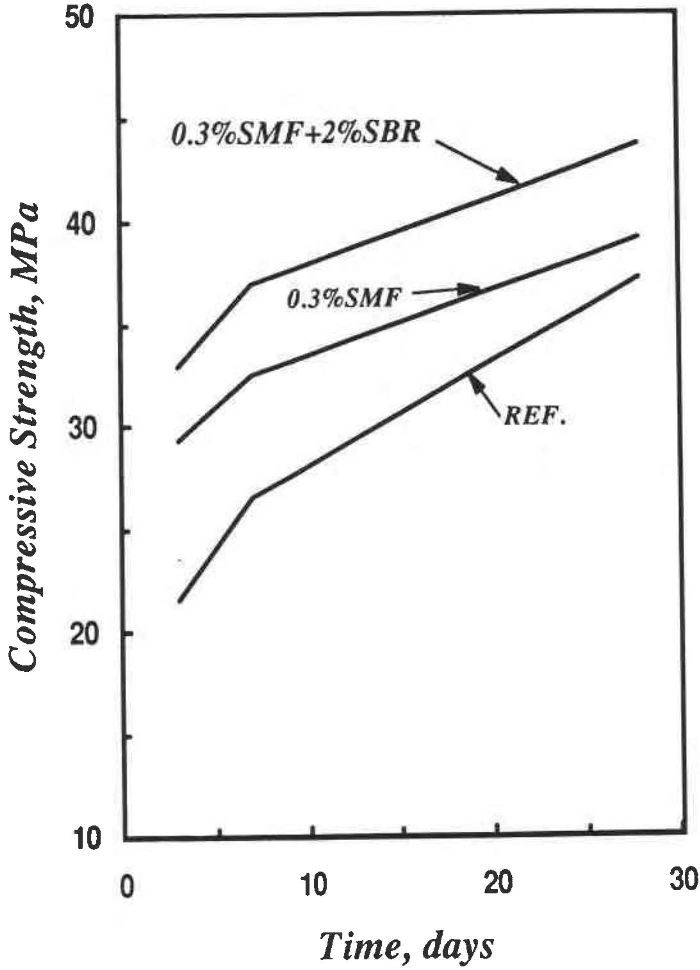

Fig. 9--Compressive strength of concrete (12.7 cm slump) containing SMF superplasticizer and SMF + SBR