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# New Generation Water-Reducing Admixture for Concrete

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## ABSTRACT

This paper is part of a preliminary investigation on the use of a new generation of water-reducing chemical admixture. Ten concrete mixes were produced for various amounts of water-reducing admixture (AD) dosages ranging from 0 - 0.7% (by mass of cement) with W/C of 0.28, 0.34, and 0.38. Workability of fresh concrete was investigated. Cylinder concrete specimens were made for evaluation of compressive strength, ultrasonic pulse velocity (V), and dynamic modulus of elasticity ($E_d$). Prism concrete specimens were made for evaluation of length change. Tests were conducted at 1, 7, 28, and 56 days. Generally all mixes containing AD achieved higher strength than the control mix without AD. The presence of AD caused a reduction in shrinkage. Correlations between the various properties were also attempted. Recommendations for using a higher dosage of AD and different mix proportions were proposed.

## INTRODUCTION

With the advent of water reducing chemical admixture as well as high-range water reducing and air-entraining chemical admixtures, concrete technology is improving significantly since around 1980. High-range water reducing and air-entraining chemical admixtures are used to produce concrete of higher strength, obtained a specified strength at lower W/C, or increase the slump of a given mixture without an increase in water content. Also, development of new generation water reducing admixtures is continuing to meet with the necessary requirement of the ready-mixed as well as the precast concrete industries (Mitsui et al 1994, Izumi et al 2003)**.** For example, by using a specially designed polycarboxylate ether polymer based superplasticizer, it became possible to accelerate the strength development at the very early stage of cement hydration. With the advent of such an admixture, it is now possible to develop a zero energy system that allows eliminating the energy requirements for placing, consolidation and heat curing of concrete in pre-cast applications (Demirboga et al (2004).

A new hybrid type superplasticizer with two different lengths of polyethylene oxide (PEO) side chains is also a new polycarboxylate derivative. The moderation of PEO amount can maximize fluidity and minimize setting retardation. This new generation superplasticizer leads to develop a stable workability of pre-cast concrete, ready mixed concrete, and high performance concrete. It has been found that the new hybrid type superplasticizer, which is a polycarboxylate type polymer with polyethylene oxide side chains, provides both of viscosity lowering ability and flowing ability. This new superplasticizer possesses several components which adsorb to cement particle very fast, but also adsorb very slowly. This technology can stabilize the adsorption properties of superplasticizer which makes lower of viscosity and a better flowing ability of mortar possible (Izumi et al 2003). In recent years, polycarboxylate based superplasticizer has been used for the purpose of producing high strength concrete and high fluidity concrete. This kind of superplasticizer is a safe chemical admixture for health, because it contains no formaldehyde, so its application is expected to expand in the future. However, a retarding property of this type of superplasticizer has caused rare application in cement based pre-cast products. Therefore, with optimization of the chemical structure of polycarboxylated copolymer, a novel polycaboxylate based SP powder is also developed (Tsukada et al 2003)**.** Investigations are still necessary to develop better chemical admixtures to mitigate the negative influences of superplasticizer. Durability based studies are also necessary to check the long-term durability of the chemical admixtures in various exposure conditions.

In this study, some selected properties of concrete having various dosages of a new generation modified polycarboxylic based superplasticizer are investigated. The properties of concrete investigated include workability, density, compressive strength, absorption, ultrasonic pulse velocity and drying shrinkage. The dosage of chemical admixtures varied from 0 - 0.7 % by mass of cement.

## EXPERIMENTAL

### Materials

The constituents of mixes were Portland cement (PC), water, fine aggregate and coarse aggregate. The PC complied with EN 197-1. The chemical composition and other properties of cement used in this study are summarized in **Table 1**. The fine aggregate used conformed to BS EN 12620: 2002, and 10 mm nominal size crushed and washed stone was used as coarse aggregate. The water-reducing admixture (AD) used was a liquid based on a modified polycarboxilic ether. The AD conformed to Types A and F Admixtures of BS EN 934-2:2001.

### Mixtures Proportions

A total of 10 mixtures were investigated to understand the performance of concrete containing a relatively new high-range water-reducing admixture. Details of all mixtures are given in **Table 2.** Mixtures 1 to 3 had water to cement ratio of 0.38 and three different dosages of admixture (AD), 0.30%, 0.35% and 0.40% (by mass of cement) respectively. In mixtures 4 to 6, the water to cement ratio was 0.34 and the dosages of admixtures were 0.45%, 0.50% and 0.55% respectively. A low water to cement ratio of 0.28 was used in mixes 7 to 10 and the AD dosages were 0%, 0.60%, 0.65% and 0.70% respectively. Properties of concrete investigated were, workability, density, compressive strength, ultrasonic pulse velocity, dynamic modulus of elasticity and drying shrinkage.

**Table 1: Composition and Properties of Portland Cement**

| Items | Unit | PC |
|---|---|---|
| $SiO_2$ | % | 20.2 |
| $Al_2O_3$ | % | 4.2 |
| $Fe_2O_3$ | % | 2 |
| CaO | % | 63.9 |
| MgO | % | 2.1 |
| $SO_3$ | % | 3 |
| $Na_2O$ | % | 0.14 |
| $K_2O$ | % | 0.68 |
| Insoluble Residue | % | 0.37 |
| Loss on Ignition | % | 2.81 |
| Free Lime | % | 2.37 |
| Specific Surface Area | $m^2/kg$ | 368 |
| Residue Retained on 45 μm Sieve | % | 15.16 |
| Initial Set | Min | 115.0 |

PC: Portland cement

**Table 2: Details of Concrete Mixtures**

| Mixtures | AD (%) | W/C | Quantity ($kg/m^3$) | | | |
|---|---|---|---|---|---|---|
| | | | PC | Water | FA | CA |
| M1 | 0.30 | 0.38 | 464 | 176 | 585 | 1207 |
| M2 | 0.35 | 0.38 | 464 | 176 | 585 | 1207 |
| M3 | 0.40 | 0.38 | 464 | 176 | 585 | 1207 |
| | | | | | | |
| M4 | 0.45 | 0.34 | 473 | 161 | 596 | 1230 |
| M5 | 0.50 | 0.34 | 473 | 161 | 596 | 1230 |
| M6 | 0.55 | 0.34 | 473 | 161 | 596 | 1230 |
| | | | | | | |
| M7 | 0.00 | 0.28 | 487 | 136 | 613 | 1266 |
| M8 | 0.60 | 0.28 | 487 | 136 | 613 | 1266 |
| M9 | 0.65 | 0.28 | 487 | 136 | 613 | 1266 |
| M10 | 0.70 | 0.28 | 487 | 136 | 613 | 1266 |

PC: Portland cement; AD: Admixture in % by mass of cement; FA: fine aggregate, CA: coarse aggregate

**Casting, Curing and Testing**

Cubes of 100 mm in size and prisms of dimensions 75 mm × 75 mm × 300 mm were made. For each mix, 12 cubes and 4 prisms were prepared. Before casting of the specimens, workability of concrete was measured by slump value, the compaction factor and Vebe test. Specimens (cubes and prisms) were cast in steel moulds and placed in a mist room at $20^oC$ and 95% RH for 24 hours. Thereafter, specimens were demoulded and all cubes and two of the prisms were placed in water at 20°C. The remaining two prisms were left to air cure in a controlled chamber set at 20°C and 55% RH. The cubes were used to determine the compressive strength and the determination of dynamic modulus of elasticity ($E_d$), ultrasonic pulse velocity (UPV) and length change were conducted on the prisms. Testing was done at 1 day, 7, 14, 28 and 56 days. In addition, length change was also measured at 2 and 3 days. The determination of compressive strength, $V$, $E_d$ and length change was done according to BS EN 12390-3:2009, BS EN 12504-4:2004 BS 1881-209:1990 and BS ISO 1920-8:2009 respectively.

## RESULTS AND DISCUSSION

### Workability

The workability results are presented in **Table 3**. All mixtures exhibited very low workability. Slump values were below 20 mm and the Vebe times increased with the decrease in water content. The increase of Vebe time is particularly noticeable at water to cement ratio of 0.28. The compaction factor increases with increasing the water content. The results indicate that the dosages of AD used in this study give no remarkable improvement in workability. The low values of the slump obtained suggest that higher dosage of admixtures is recommended well above those recommended by the manufacturer, so that meaningful comparison can be made. This is particularly relevant in the case of low water to cement ratio.

**Table 3: Workability of Concrete**

| Mixtures | AD % | W/C | Slump (mm) | Vebe (s) | Compaction Factor |
|---|---|---|---|---|---|
| M1 | 0.30 | 0.38 | 20 | 4.9 | 0.86 |
| M2 | 0.35 | 0.38 | 15 | 5.3 | 0.86 |
| M3 | 0.40 | 0.38 | 20 | 5.2 | 0.81 |
| | | | | | |
| M4 | 0.45 | 0.34 | 10 | 7.9 | 0.79 |
| M5 | 0.50 | 0.34 | 10 | 8.9 | 0.80 |
| M6 | 0.55 | 0.34 | 10 | 8.3 | 0.82 |
| | | | | | |
| M7 | 0.00 | 0.28 | 0 | 33.5 | 0.78 |
| M8 | 0.60 | 0.28 | 0 | 26.8 | 0.76 |
| M9 | 0.65 | 0.28 | 5 | 24.8 | 0.75 |
| M10 | 0.70 | 0.28 | 0 | 26.6 | 0.78 |

### Compressive Strength

The compressive strength of concrete for all mixed at 28 days of water curing is shown in **Figure 1**. Using an optimum dosage of AD seems to cause an enhancement in strength compared with low or high dosage of AD (**Figure 1)**. The values of the slump obtained suggest that higher dosage of admixtures is recommended well above those used in the present investigation and well above the manufacturer recommendations, so that meaningful comparison between the strength values can be made.

**Ultrasonic Pulse Velocity (UPV)**
**Table 4** presents the ultrasonic pulse velocity data for all mixes at 1 day, 7 and 28 days of water curing. The trend in UPV is similar to that of compressive strength. Using medium dosage of AD causes an increase in UPV as compared with low and high dosage of AD.

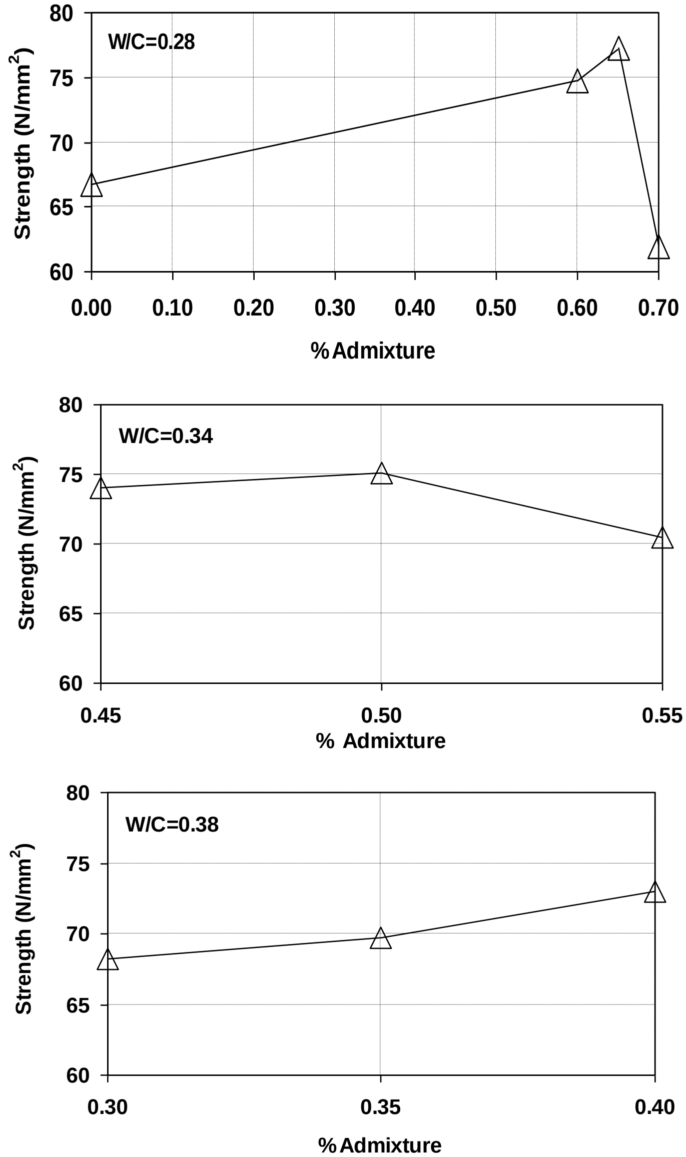



**Fig. 1. Compressive Strength of Concrete at 28 days**

The variation of compressive strength with UPV is attempted and the following exponential relationship is found between compressive strength (y in MPa) and UPV (x in m/sec). This agrees with correlation obtained elsewhere (Demirboga et al 2004).

$$y = 0.0071e^{0.0019x} \tag{1}$$

with a coefficient of correlation ($R^2$) of 0.97.

**Dynamic Modulus**

The data of dynamic modulus ($E_d$) of concrete are summarized in **Table 5**. Same as the compressive strength of concrete, the dynamic modulus increases with time. Comparing the control case (M7) with the other cases (M8, M9, and M10), it is seen that dynamic modulus is increased significantly with the addition of AD. The effect of dosage of AD is not clear as observed for the compressive strength of concrete.

**Table 4: Ultrasonic Pulse Velocity (UPV) of Mixtures**

| Mixtures | AD % | W/C | UPV (m/sec) | | |
|---|---|---|---|---|---|
| | | | 1-Day | 7-Days | 28-Days |
| M1 | 0.30 | 0.38 | 4318 | 4613 | 4726 |
| M2 | 0.35 | 0.38 | 4299 | 4630 | 4735 |
| M3 | 0.40 | 0.38 | 4340 | 4682 | 4748 |
| | | | | | |
| M4 | 0.45 | 0.34 | 4409 | 4726 | 4794 |
| M5 | 0.50 | 0.34 | 4480 | 4748 | 4817 |
| M6 | 0.55 | 0.34 | 4448 | 4735 | 4817 |
| | | | | | |
| M7 | 0.00 | 0.28 | 4310 | 4617 | 4735 |
| M8 | 0.60 | 0.28 | 4492 | 4748 | 4794 |
| M9 | 0.65 | 0.28 | 4433 | 4717 | 4798 |
| M10 | 0.70 | 0.28 | 4425 | 4708 | 4785 |

The dynamic modulus versus compressive strength data are correlated and the following logarithmic relation is found between the dynamic modulus (y in MPa) and the compressive strength of concrete (x in MPa), with a coefficient of correlation ($R^2$) of 0.85.

$$y = 9621.8\ln(x) + 3343 \quad (2)$$

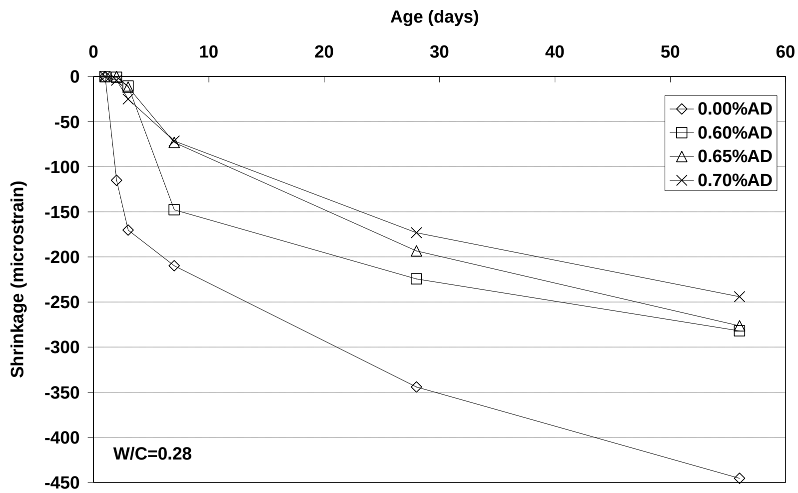
**Table 5: Dynamic Modulus of Mixtures**

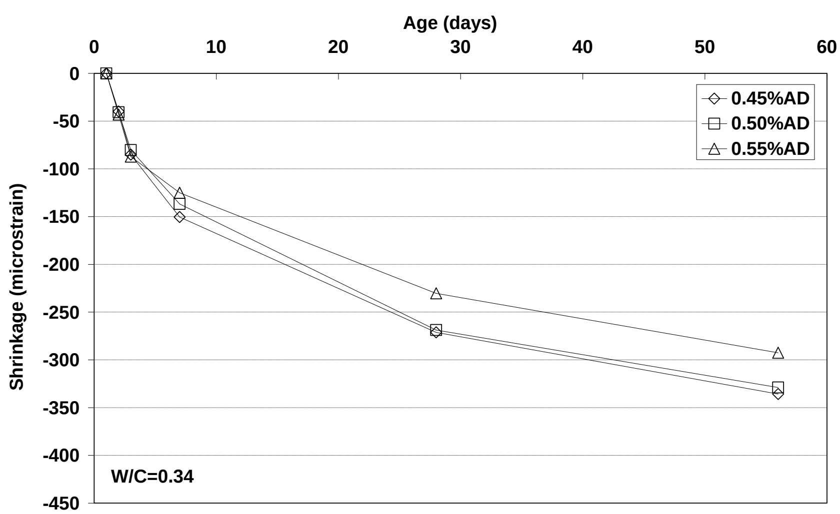
| Mixtures | AD % | W/C | $E_d$ ($kN/mm^2$) | | |
|---|---|---|---|---|---|
| | | | 1-Day | 7-Days | 28-Days |
| M1 | 0.30 | 0.38 | 34.8 | 41.5 | 42.1 |
| M2 | 0.35 | 0.38 | 33.7 | 40.5 | 41.8 |
| M3 | 0.40 | 0.38 | 36.4 | 43.1 | 43.9 |
| | | | | | |
| M4 | 0.45 | 0.34 | 37.6 | 44.2 | 45.1 |
| M5 | 0.50 | 0.34 | 39.9 | 45.0 | 45.8 |
| M6 | 0.55 | 0.34 | 36.7 | 42.7 | 43.4 |
| | | | | | |
| M7 | 0.00 | 0.28 | 35.2 | 41.6 | 41.7 |

| | | | | | |
|---|---|---|---|---|---|
| M8 | 0.60 | 0.28 | 39.1 | 44.5 | 45.3 |
| M9 | 0.65 | 0.28 | 38.4 | 44.2 | 45.0 |
| M10 | 0.70 | 0.28 | 38.2 | 45.7 | 46.6 |

**Drying Shrinkage**

Drying shrinkage of all mixes is shown in **Figure 2**. The results suggest that the use of AD cause a reduction in shrinkage and higher AD dosage reduces the shrinkage even further. As can be expected, most of the shrinkage occurs during the first 28 days.



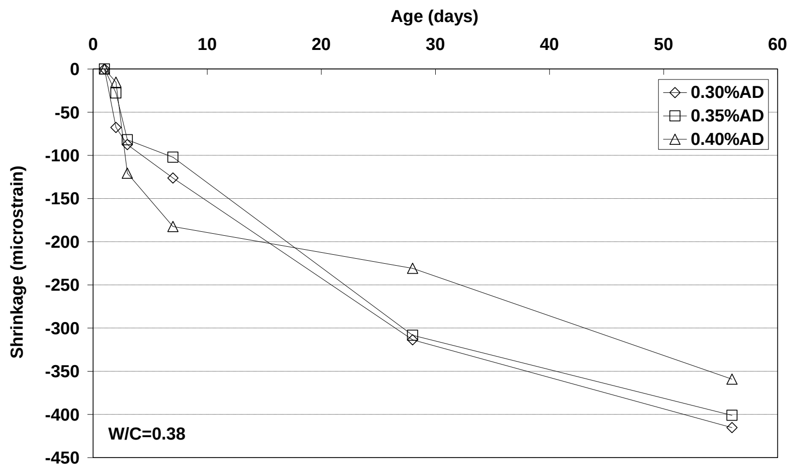



**Fig. 2. Drying Shrinkage of Concrete**

The change in shrinkage with time can be described by the following equation (ACI 1992, Huo et al 2001):

$$\varepsilon = \frac{-bt}{a+t} \tag{3}$$

where ε is the shrinkage in micro-strain, *t* is time in days, *a* is a constant related to strength and *b* is another constant related to ultimate shrinkage values and other factors including environmental conditions, specimens size and strength. Fitting the above equation to the experimental data, values of *a* and *b* were obtained for each of the mixes. These values are summarized in **Table 6** with their correlation coefficients ($R^2$). The values of *b* are higher than those reported elsewhere (Huo et al 2001, Khatib 2004), partly due to the relatively high cement content in the mixes. There does not seem to be a trend in the values of *a* and *b* with respect to %AD, which suggests that the mix design should be altered so that full compaction can be obtained.

**Table 6: Coefficients *a* and *b***

| Mixes | AD % | *a* | *b* | $R^2$ |
|---|---|---|---|---|
| M1 | 0.30 | 22.9 | 582 | 1.0 |
| M2 | 0.35 | 32.7 | 641 | 0.96 |
| M3 | 0.40 | 17.4 | 454 | 0.96 |
| | | | | |
| M4 | 0.45 | 15.7 | 429 | 0.94 |
| M5 | 0.50 | 16.7 | 427 | 0.94 |
| M6 | 0.55 | 14.8 | 367 | 0.98 |
| | | | | |
| M7 | 0.00 | 10.5 | 518 | 1.0 |
| M8 | 0.60 | 28.1 | 431 | 0.81 |
| M9 | 0.65 | 106 | 830 | 0.94 |
| M10 | 0.70 | 56 | 495 | 0.95 |

## CONCLUSIONS AND RECOMMENDATIONS

Generally all mixes containing admixtures achieved higher strength than the control mix without any admixtures. The presence of admixture caused a reduction in shrinkage. An exponential relationship between strength and ultrasonic pulse velocity yielded a coefficient of correlation of 0.97 suggesting this relationship is appropriate.

Based on the preliminary results of this investigation, it is strongly recommended to use higher dosage of admixture, than those used in the present work so that so adequate slump can be obtained. In the present work the dosages used were those recommended by the manufacturer but the low water to cement ratio in the mixes exacerbated the effect and dosages of admixtures above those recommended should be used

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