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STUDY REPORT

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An Evaluation of Concrete Made Using Recycled Slurry From Concrete Plant Operations as Mix Water

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Preface

This report is intended for ready-mix plant operators, project engineers, and environmental engineers.

Acknowledgments

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AN EVALUATION OF CONCRETE MADE USING RECYCLED SLURRY FROM CONCRETE PLANT OPERATIONS AS MIX WATER

BRANZ Study Report SR74 **S. Park and D. Chisholm**

REFERENCE

Park, S. and Chisholm, D. 1996. An Evaluation of Concrete Made Using Recycled Slurry From Concrete Plant Operations as Mix Water. Building Research Association of New Zealand. Study Report SR 74, Judgeford, New Zealand.

KEYWORDS

Slurry; Compressive Strength; Shrinkage; Recycled.

ABSTRACT

The use of recycled slurry via a sample from concrete plant operations was investigated. A total of eleven different concrete mixes were made, with different design strengths and different levels of mix water replacement, to determine the effect that recycled slurry has on concrete. The mixes were made such that they had the same slump and then other properties were investigated. These included fresh density, yield and air content of the fresh concrete; and compressive strength, hardened density, chloride ion-penetration resistance and drying shrinkage of the hardened concrete.

Using slurry in concrete is becoming an increasingly attractive, even necessary option, as the cost of disposing of waste concrete increases and/or the availability of disposal sites for waste concrete decreases. Given the results of the tests carried out in this project it was concluded that the use of recycled slurry is a viable option, although a strength decrease may be encountered, especially with higher-strength mixes.

Contents

1.0 INTRODUCTION

Since the introduction of the Resource Management Act in 1991 (New Zealand Government, 1991), there has been increasing pressure for industry to control its resource usage and in particular, industrial waste output.

Ready mix concrete plant operations are large consumers of water. Feger (1990) estimates that approximately 200 litres of water are used to produce one cubic metre of concrete from a central batch plant. The figure from a truck mix plant is higher, at 300 litres. In addition approximately 500 - 1500 litres of water are used to wash down the plant and yard at the end of each production day, plus 100 litres to wash out each mixer - the central mixer and every truck used that day. The actual amount of water added to the mixer (mix water) for each cubic metre produced is approximately 125 litres.

The recent water shortage in the Auckland area showed what an essential resource it is. Most ready mix plants collect water from yard operations and recycle it as wash water. The water is collected via a series of ponds with the solids portion (aggregate, sand, cement fines etc.) being recovered periodically to be dumped as waste. In some city plants the recycled water is also reused as mix water.

This project evaluates the reuse of 'slurry water'. Slurry water comprises the 'below 300 μm' portion of the settled solids from the recycled water mixed with a quantity of recycled water to make it into a slurry form to ease handling. The sample of slurry used in this project was supplied from the Penrose ready-mix concrete plant of W. Stevenson & Sons Ltd, Auckland. This plant operation was upgraded in 1995 and recycled slurry is routinely used at up to 40% of mix water for all mixes except exposed aggregate mixes.

The Stevenson plant also recycles returned waste concrete through a commercial 'Rapid Reclaimer', which separates out the aggregate and coarse sand portions from waste concrete. The remaining liquid and fines go into the wash water recovery system and end up in the slurry water component. The recycled sand and aggregate can be regraded through the concrete aggregate processing plant.

Other plants dispose of returned concrete once it has been allowed to harden into a mass, and incur transport and dumping charges. Albeck and Baumgartner (1993) estimate that in Germany the average volume of returned or residual concrete is approximately 2.5% of the entire production volume. For the New Zealand ready-mix concrete industry this would be equivalent to approximately 53,000 m^3 of concrete for the 1995 year, a very large volume of concrete to waste. This figure appears high, but the actual New Zealand figure is not known. Even at 1% of the entire production volume though, the figure is about 21,000 m^3 for the 1995 year for the total New Zealand ready-mix concrete production.

The solids content of the slurry is critical in allowing the slurry to be recovered from the storage tank and introduced at a consistent composition into the concrete mixer. At the Stevenson plant the solids portion of the slurry is kept in suspension by slush pumps and transported up to the mixer by auger and pump. If the solids portion gets too high the system is unable to maintain them in suspension and they settle out.

Approximately 80 litres of slurry were supplied by W. Stevenson & Sons Ltd for the project.

2.0 METHOD

Eleven concrete mixes were made to determine the performance of three 'standard' concretes with different levels of mix water replaced with recycled slurry. The three 'standard' concretes had design compressive strengths of 17.5 MPa, 35 MPa, and 50 MPa respectively. The level of mix water replacement with recycled slurry for the eleven mixes is given in Table 1. Tables 4a, 4b and 4c give the designs for the 'standard' concrete mixes.

	Percentage Mix Water Replaced With Recycled Slurry			
Mix Design Strength (MPa)	0%	30%	50%	100%
17.5	✓ 17.5/C	✓ 17.5/3	✓ 17.5/5	✓ 17.5/10
35	✓ 35/C	✗	✓ 35/5	✓ 35/10
50	✓ 50/C	✓ 50/3	✓ 50/5	✓ 50/10

Table 1 : Mixes Used

A sub-sample of slurry was weighed then dried to determine the water and solids content, and a sieve analysis was carried out on the dried solid particles to NZS 3111 (SANZ, 1986).

The slurry replacement was done by weight. Before each mix where replacement of mix water was to occur, a sufficient amount of slurry mix water was prepared with the correct level of slurry measured in by weight. Care was taken to thoroughly mix the slurry with a circulating pump to ensure that the solids were evenly distributed throughout, both before adding the slurry to fresh water, and before adding the slurry water to the mix.

Fifty-litre mixes were made up in the laboratory pan mixer. The following fresh concrete tests were carried out on all of the mixes to the methods stated in NZS 3112: Part 1 (SANZ, 1986):

- Slump (a slump of 80 mm was targeted for the mixes)
- Density
- Yield
- Air content

The temperature of each mix was also recorded.

Concrete cylinders were prepared to the method given in NZS 3112: Part 2 (SANZ, 1986), for the purpose of compression testing three cylinders at each of three, seven, and twenty-eight days, also to NZS 3112: Part 2 (SANZ, 1986).

At the same time that the compression testing was carried out, the density of each cylinder was measured by weighing the saturated cylinder in air and water to the method given in NZS 3112: Part 3 (SANZ, 1986).

Additional cylinders were prepared from the 50 MPa mixes to determine an electrical indication of concrete's ability to resist chloride ion penetration, according to ASTM C1202-91 (American Society for Testing and Materials, 1991), also known as the rapid chloride test.

Three 75 x 75 x 295 mm prisms were made from each of the 17.5 MPa and 50 MPa mixes to determine the drying shrinkage of the concrete to AS 1012.13 (SA, 1992). It was not felt necessary to carry out shrinkage testing on the 35 MPa mixes as the results for these were likely to fall between the other two extremes.

3.0 RESULTS

3.1 Slurry Moisture Content

The water-to-solids ratio of the slurry was found to be 81:19 when drying a 21 kg (approximately) sample of slurry at 105°C for approximately four days. The specific gravity of the slurry was approximately 1.14.

3.2 Slurry Solids Particle Analysis

The sieve analysis of the slurry solids is given in Tables 2a & 2b. A chemical analysis of this solids portion is given in Table 3.

Sieve Size (μm)	Mass Retained (g)	% Retained	Cumulative % Retained	% Passing
600	0.5	0.3	0.3	99.7
300	4.8	2.8	3.1	96.9
150	45.1	26.3	29.4	70.6
75	20.2	11.8	41.2	58.8
45	12.1	7.1	48.3	51.7
Pan	86.8	50.7	99.0	0.0

Table 2a : Slurry Solids Sieve Analysis (down to 45 μm sieve size)

Sieve Size (μm)	% Retained	Cumulative % Retained	% Passing
37	11.36	11.36	88.64
28	3.34	14.70	85.30
21	4.65	19.35	80.65
15	4.03	23.38	76.62
11	3.34	26.72	73.28
Pan	73.78	100.50	0.00

Table 2b: Slurry Solids Sieve Analysis (less than 45 μm sieve size)

Parameter	Unit	Value
pH	-	12.5
Oxidisable Substances	mg/L	5.7; 5.3
Nitrate	mg NO_3-N/L*	0.31
Ammonia	mg NH_4^+-N/L†	0.076
Sulphate	mg SO_4^{2-}/L	74
Chloride	mg Cl^-/L	50
Calcium	mg/L	560; 550
Sodium	mg/L	55
Potassium	mg/L	66
Magnesium	mg/L	<0.1
Zinc	mg/L	0.02
Lead	mg/L	<0.01

* *Milligrams of nitrogen as nitrate per litre*
† *Milligrams of nitrogen as ammonia per litre*

Table 3: Chemical Analysis of Slurry Solids

3.3 Concrete Mix Details and Fresh Concrete Test Results

The concrete mixes used are given in Tables 4a, 4b and 4c, along with their fresh concrete test results.

Materials	Description	17.5/C	17.5/3	17.5/5	17.5/10
Date Mixed		12/01/96	23/01/96	16/01/96	16/01/96
19 mm Aggregate (kg/m^3)	Belmont	545	545	545	545
13 mm Aggregate (kg/m^3)	Belmont	545	545	545	545
Sand (kg/m^3)	Belmont	830	830	830	830
Cement (kg/m^3)	Golden Bay	220	220	220	220
Water Reducer (l/m^3)	Sika Plastiment BV 40	0.550	0.550	0.550	0.550
Air Entrainer (l/m^3)	Sika Frobe	0.100	0.100	0.150	0.100
Total Water (l/m^3)		167	171	173	180
Water/Cement Ratio		0.76	0.78	0.79	0.82
Air (%)		4.8	4.6	4.6	4.0
Slump (mm)		80	80	100	80
Fresh Density (kg/m^3)		2320	2300	2300	2310
Measured Yield		0.993	1.005	1.008	1.007
Mix Temperature (°C)		25.0	24.0	21.0	21.0

Table 4a: 17.5 MPa Mix Details and Fresh Concrete Properties

Materials	Description	35/C	35/5	35/10
Date Mixed		21/12/95	23/01/96	21/12/95
19 mm Aggregate (kg/m^3)	Belmont	653	545	653
13 mm Aggregate (kg/m^3)	Belmont	436	545	436
Sand (kg/m^3)	Belmont	865	835	865
Cement (kg/m^3)	Golden Bay	290	290	290
Water Reducer (l/m^3)	Sika Plastiment BV 40	0.725	0.725	0.725
Total Water (l/m^3)		167	174	177
Water/Cement Ratio		0.59	0.60	0.63
Air (%)		1.8	1.7	1.6
Slump (mm)		60	80	70
Fresh Density (kg/m^3)		2370	2380	2370
Measured Yield		1.021	1.002	1.025
Mix Temperature (°C)		24.0	24.0	24.0

Table 4b: 35 MPa Mix Details and Fresh Concrete Properties

Materials	Description	50/C	50/3	50/5	50/10
Date Mixed		23/01/96	26/01/96	26/01/96	30/01/96
19 mm Aggregate (kg/m^3)	Belmont	545	545	545	545
13 mm Aggregate (kg/m^3)	Belmont	545	545	545	545
Sand (kg/m^3)	Belmont	760	760	740	720
Cement (kg/m^3)	Golden Bay	380	380	380	380
Water Reducer (l/m^3)	Sika Plastiment BV 40	0.725	0.725	0.725	0.725
Total Water (l/m^3)		179	181	185	205
Water/Cement Ratio		0.47	0.48	0.49	0.55
Air (%)		1.6	1.7	1.7	1.4
Slump (mm)		80	80	80	80
Fresh Density (kg/m^3)		2390	2390	2390	2370
Yield		1.008	1.010	1.005	1.011
Mix Temperature (°C)		24.0	20.0	20.0	23.0

Table 4c: 50 MPa Mix Details and Fresh Concrete Properties

3.4 Compressive Strength Results

The averaged results of the compressive strength requirements are given in Table 5, along with the average hardened densities of the cylinders. The compressive strength gain is shown graphically in Figures 1a, 1b and 1c.

Mix		Age (Days)		
		3	7	28
17.5/C	Compression (MPa)	8.5	13.0	18.5
	Range (MPa)	0.4	0.8	1.3
	Density (kg/m^3)	2350	2360	2360
17.5/3	Compression (MPa)	9.0	13.0	16.5
	Range (MPa)	0.3	0.3	0.5
	Density (kg/m^3)	2320	2320	2330
17.5/5	Compression (MPa)	8.0	12.5*	16.0
	Range (MPa)	0.3	0.6	0.7
	Density (kg/m^3)	2330	2320	2330
17.5/10	Compression (MPa)	10.0	16.0*	19.0
	Range (MPa)	0.2	0.8	0.2
	Density (kg/m^3)	2350	2340	2340
35/C	Compression (MPa)		32.0*	40.5
	Range (MPa)		0.6	1.8
	Density (kg/m^3)		2420	2420
35/5	Compression (MPa)	19.5	28.0	35.0
	Range (MPa)	0.3	0.2	2.1
	Density (kg/m^3)	2390	2390	2390
35/10	Compression (MPa)		26.5*	35.5
	Range (MPa)		0.7	1.5
	Density (kg/m^3)		2390	2390
50/C	Compression (MPa)	34.0	43.5	55.0
	Range (MPa)	1.4	3.1	2.1
	Density (kg/m^3)	2420	2420	2420
50/3	Compression (MPa)	32.5	44.0	52.0
	Range (MPa)	1.1	2.9	1.2
	Density (kg/m^3)	2410	2410	2420
50/5	Compression (MPa)	32.0	44.0	52.0
	Range (MPa)	0.4	0.3	0.9
	Density (kg/m^3)	2410	2410	2420
50/10	Compression (MPa)	27.0	30.5	45.5
	Range (MPa)	4.4	1.1	6.3
	Density (kg/m^3)	2400	2390	2390

* Cylinders tested at 8 days

Note: Range calculated from actual compressive strengths for each group of three cylinders

Table 5: Mean Compression Strengths and Densities of all Mixes (mean of 3 cylinders per mix)

3.5 Rapid Chloride Penetration Test Results

The results of the rapid chloride testing carried out on the 50 MPa mixes are given in Table 6.

Mix	Charge Passed (Coulombs) Adjusted Mean*	Coefficient of Variation within Test (%)
50/C	4064	2.6
50/3	4238	5.9
50/5	4316	7.6
50/10	4581	0.6

* Mean adjusted in accordance with ASTM C 1202 clause 11.2 for sample diameters other than 95 mm

Table 6: 50 MPa Mixes, Mean Current Passed (mean of 3 samples per mix)

3.6 Shrinkage Beam Results

Tables 7a and 7b give the mean beam shrinkage values as determined for the 17.5 MPa and 50 MPa mixes respectively. Figures 2a and 2b show this information graphically.

Sample	17.5/C	17.5/3	17.5/5	17.5/10
Day	Mean Shrinkage (Microstrain)			
0	0	0	0	0
7	290	320	220	230
14	430	490	450	460
21	570	600	550	550
28	630	660	630	620
56	730	780	710	750

Table 7a: Mean Shrinkage of 17.5 MPa Mixes

Sample	50/C	50/3	50/5	50/10
Day	Mean Shrinkage (Microstrain)			
0	0	0	0	0
7	350	340	310	330
14	460	480	460	460
21	550	560	560	560
28	600	650	630	640
56	740	760	750	780

Table 7b: Mean Shrinkage of 50 MPa Mixes

4.0 DISCUSSION

4.1 Fresh Concrete Tests

The mixes behaved almost as predicted.

As can be seen by examining Tables 4a, 4b and 4c, the fresh concrete properties of each mix strength were consistent over all the mixes. Air contents of about 4.5% for the 17.5 MPa mixes and 2.0% for the others were achieved, as targeted. The targeted slump of 80mm was achieved in almost every case. The variations that can be seen in the results are within acceptable levels. Fresh concrete densities were constant within each mix design.

In determining the initial mix quantities it was assumed that the target added water would simply be replaced by the quantity of water in the slurry. In fact, as the percentage of slurry replacement increased so did the amount of water required to achieve the target slump. This was more noticeable in the higher-strength mixes.

It was also assumed that the yield would not require adjustment for the solids content of the slurry. While this was justified for the lower strength mixes, the first 50 MPa mix with 100% slurry replacement (50/10) had to be reviewed and repeated with 40 kg less sand, due to the fact that it over-yield. This over-yield was due to a combination of higher water demand due to the higher fines in the mix from both the increased slurry fines and cement, and the increased slurry solid content which itself increased the yield. The 50/5 mix was also adjusted to prevent over-yield.

4.2 Compressive Strengths and Hardened Densities

Table 5 and Figures 1a, 1b and 1c show that the control mixes all reached strengths greater than their design strengths. They also show that as the mix water was replaced with recycled slurry there was, generally, a noticeable drop in strength. This did not always hold true, as can be seen from the 17.5 MPa results, where the 17.5/10 mix has the highest strength results of all the 17.5 MPa mixes at all ages. This cannot be taken as significant however, as it was a one off test, and a greater test history must be built up before any definitive statements can be made.

As noted in 4.1 above, as the percentage slurry replacement increased, so did the water demand. This adversely affected the water-cement ratio, and hence the concrete strengths. This can be most clearly seen with the 50 MPa mixes.

Although the strengths were reduced, as expected, the inclusion of recycled slurry appears to have had no effect on the hardened densities of the concrete, as can be seen in Table 5.

4.3 Rapid Chloride Penetration Tests

The rapid chloride test has the ability to measure indirectly the pore-filling function of the concrete mortar component. A lower charge passed reflects an increase filling.

Table 6 gives a charge passed of 4064 coulombs for the control mix. This is a typical figure for such a mix. As can also be seen from Table 6, as the level of water replacement is increased, so does the charge passed.

This reflects the reduction in strength. This is to be expected as the slurry fines provide no compensating pore-filling function, they are an inert filler. The increase in current passed from the 50/C mix to the 50/10 mix is not considered significant for this level of chloride ion penetration.

4.4 Concrete Drying Shrinkage

As can be seen from Tables 7a and 7b, and Figures 2a and 2b, the replacement of mix water with recycled slurry had no significant effect on the shrinkage of the concrete. It is also noteworthy that there was no significant difference between the 17.5 MPa mix results and those for the 50 MPa mix.

5.0 CONCLUSIONS

Mixes of three different design strengths were mixed in the laboratory pan mixer to evaluate the performance of concrete made using recycled slurry from concrete plant operations as mix water. A slurry with a 20% solids content was used. The three design strengths were 17.5 MPa, 35 MPa and 50 MPa. These strengths were chosen to cover as broad a range of actual mixes as possible. Three or four mixes were made at each design strength with four different levels of mix water replacement (0%, 30%, 50%, 100%) to determine the effect that this had.

From the results of the tests carried out, the main effect of replacing mix water with recycled slurry was observed to be a reduction in strength. This strength loss is to be expected given the increased water demand to achieve slump as mix water replacement was increased. This was most noticeable with the 50 MPa mixes, and not so noticeable at the lower strength 17.5 MPa mixes.

Other tests, including air content, fresh density, hardened density, rapid chloride ion penetration and shrinkage, were not significantly affected by the inclusion of recycled slurry in the mixes. However, mix yield needs to be adjusted for the solids content of the slurry where the slurry replacement level is 50% or greater.

Given these results, it is clear that the practice of using recycled slurry to replace mix water is a valid proposition. For higher strength mixes some strength loss may be expected, which needs to be allowed for.

6.0 SCOPE FOR FURTHER WORK

Areas that were not investigated in this programme in which it is felt that further work should be carried out include:

- Effect of slurry on setting times
- Effect of different slurries on parameters tested here
- Mix design compensation for solids content of slurry

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8.0 FIGURES

Figure 1a: 17.5 MPa Mixes, Strength Development

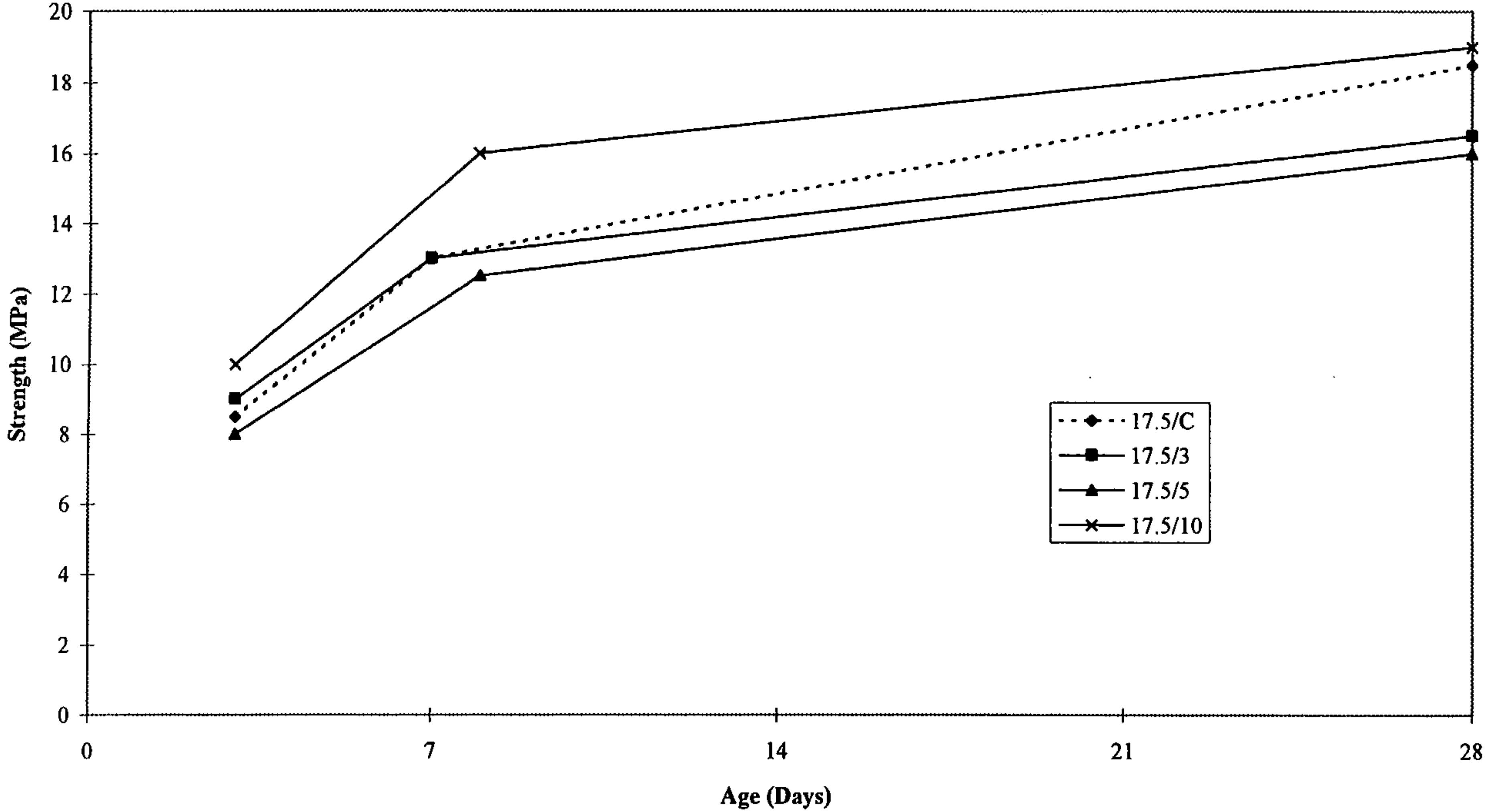


Figure 1b: 35 MPa Mixes, Strength Development

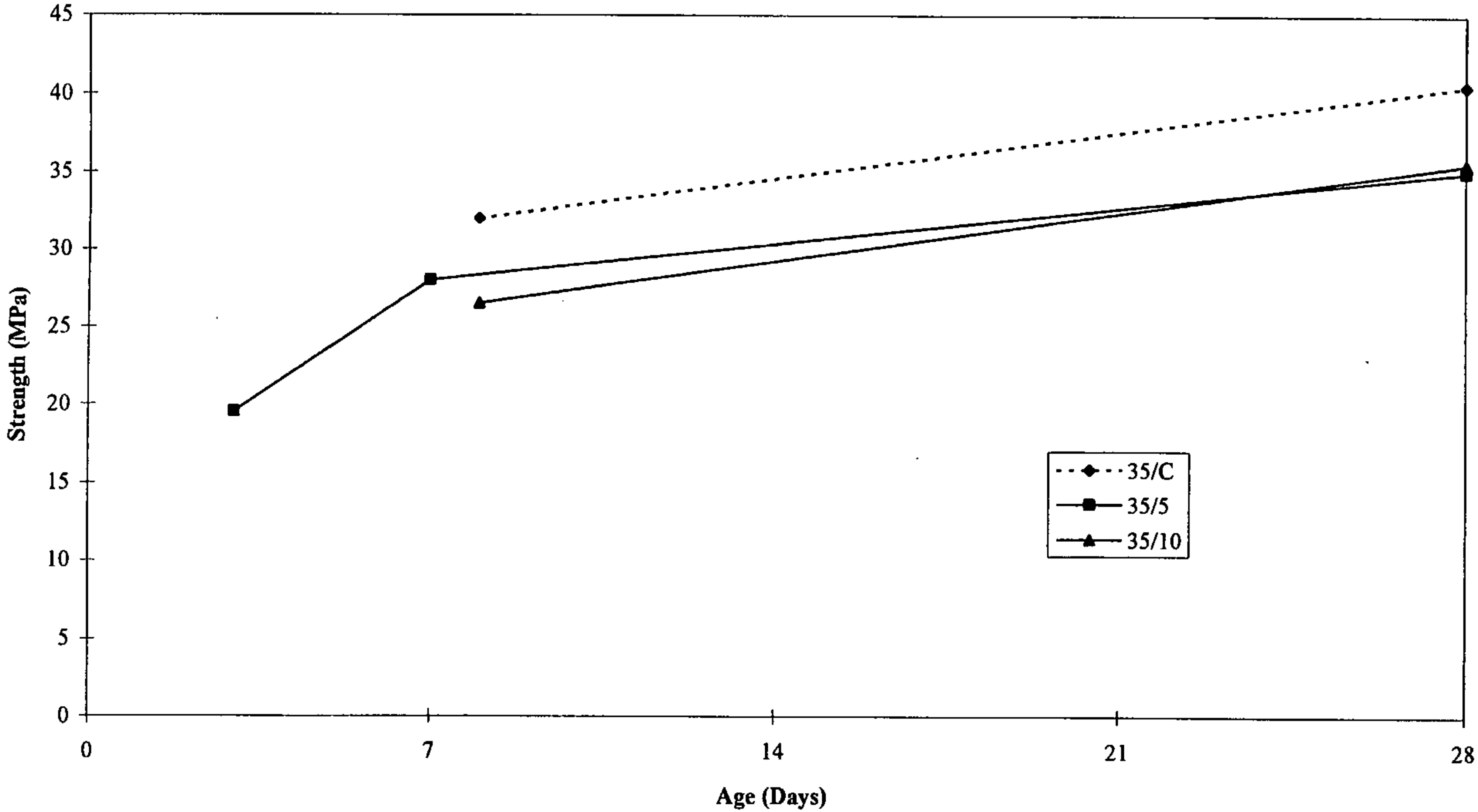


Figure 1c: 50 MPa Mixes, Strength Development

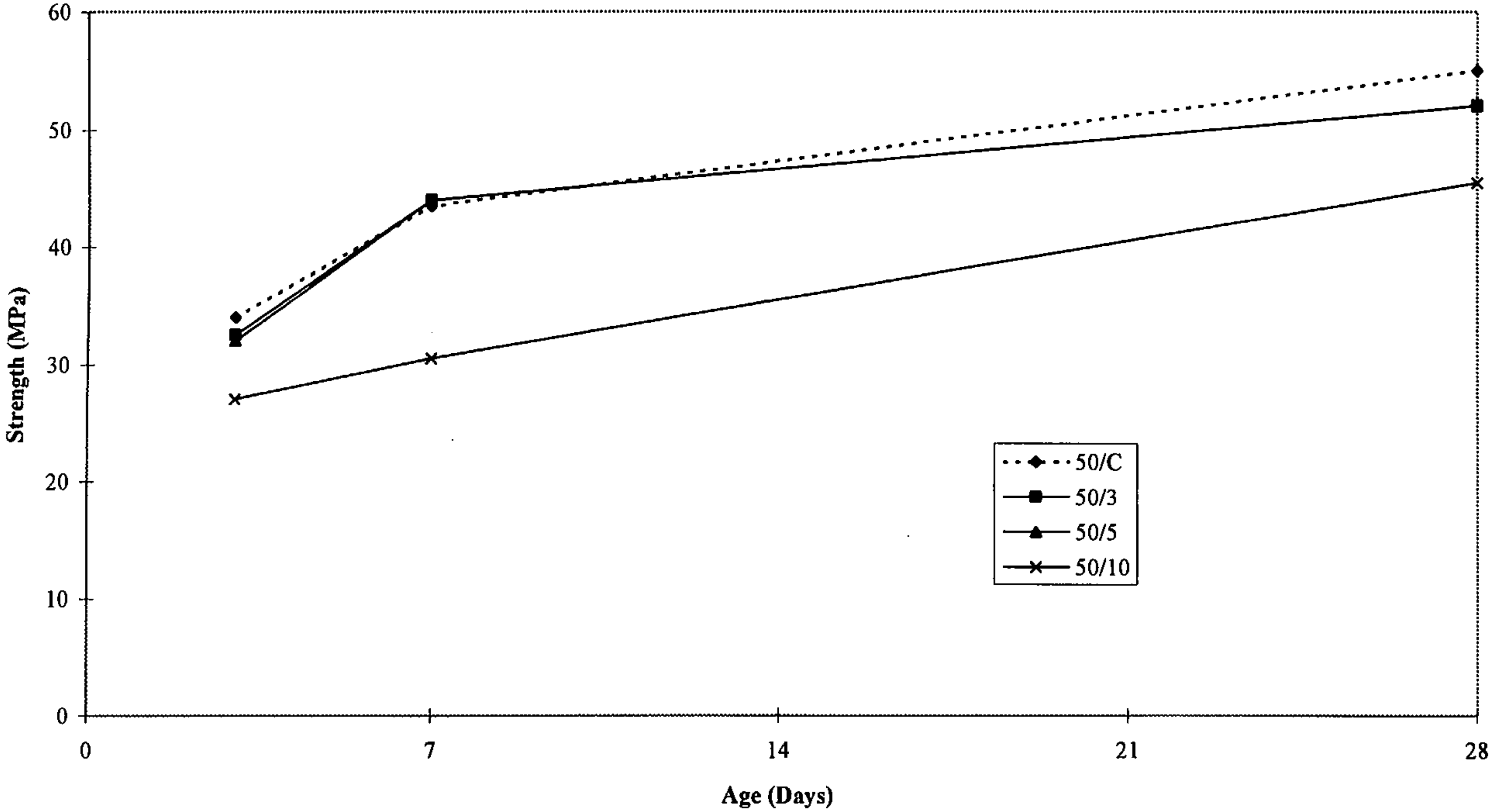


Figure 2a: Beam Shrinkage of 17.5 MPa Mixes

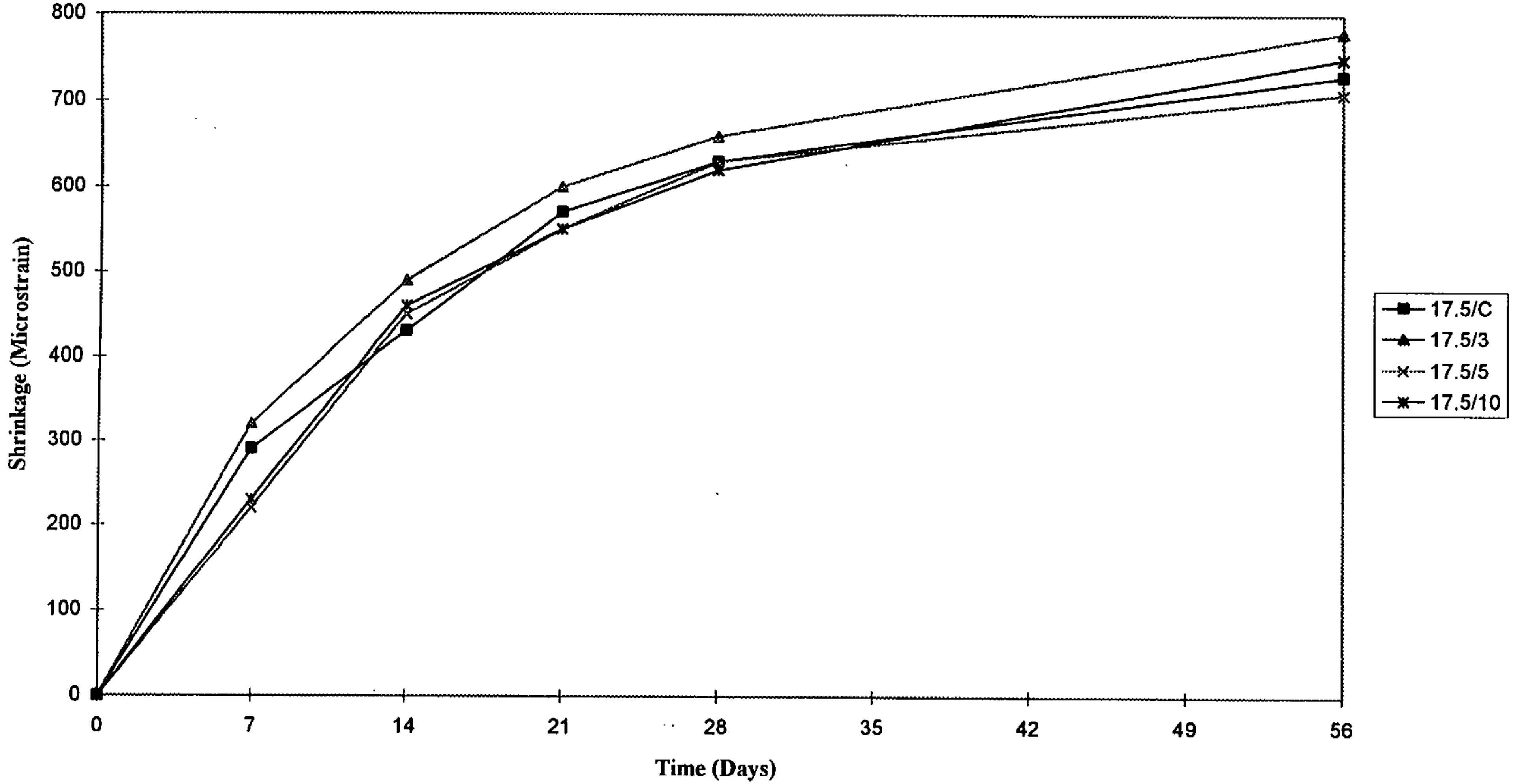
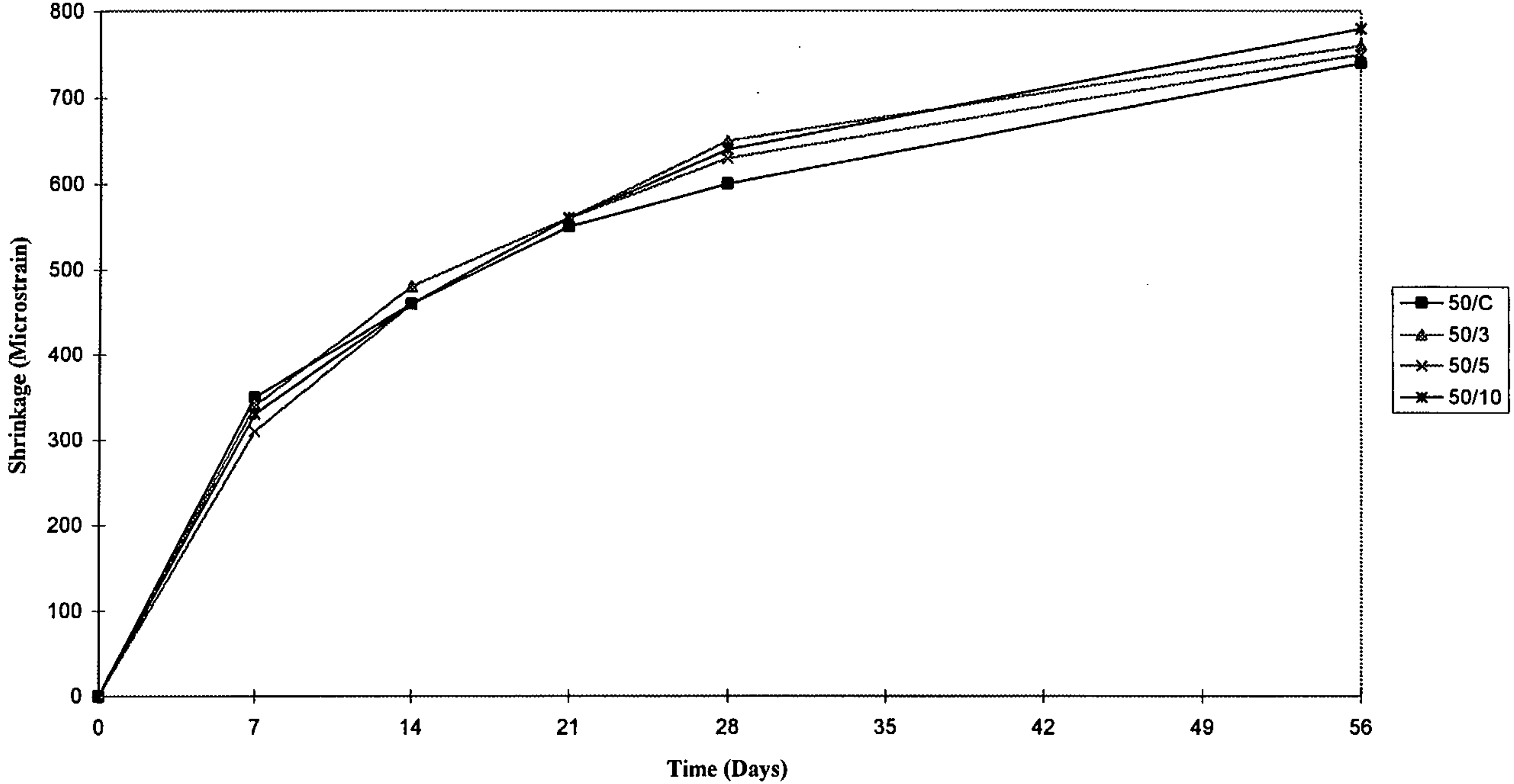


Figure 2b: Beam Shrinkage of 50 MPa Mixes



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