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Development of Fast-Track Concrete - 2

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16. Abstract

The project described herein pertains to the development of very high early strength concrete, herein referred to as fast track concrete, for rapid repair of highway pavements. This project is a sequel to an earlier study. The objective of the former project was to develop the base mix design for the fast track concrete, establish in-place field, monitoring procedures, and demonstrate the fast track technology in actual field applications. The scope of the earlier project was limited to a single cement brand and type. The objective of the study presented here was to explore the capability of Portland cement types I and III in achieving fast track properties. In doing so the project involved development of fast track concrete with a number of different cement brands currently use in New Jersey. The concrete developed in this project will be employed in full–depth repair of jointed concrete pavement slabs.

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INTRODUCTION

The project described herein pertains to the development of very high early strength concrete, herein referred to as fast track concrete, for rapid repair of highway pavements. This project is a sequel to an earlier study. The objective of the former project was to develop the base mix design for the fast track concrete, establish in-place field monitoring procedures, and demonstrate the fast track technology in actual field applications. The scope of the earlier project was limited to a single cement brand and type. The objective of the study presented here was to explore the capability of Portland cement types I and III in achieving fast track properties. In doing so the project involved development of fast track concrete with a number of different cement brands currently in use in New Jersey. The concrete developed in this project will be employed in full-depth repair of jointed concrete pavement slabs. The primary requirements for the concrete were:

- Achieving a compressive strength, f_c', of about 2000 to 3000 psi in 6 to 7 hours after pouring and placement operations.
- Development of a modulus of rupture, f_r , of about 350 psi in 6 to 7 hours.
- Use of locally available materials and normal aggregate gradations, i.e. Type I Portland cement.
- Use of accelerators limited to non-chloride based admixtures.
- Workability for placement and finishing operations.

The requirement for achieving a sufficient level of flexural strength was prescribed as a safeguard against premature cracking due to heavy truck traffic volume.

MATURITY METHOD

Maturity technique was employed as a simplified in-place test method for rapid evaluation of strength in pavements. This technique is based on the measured temperature history of concrete during the curing period. The combined effects of time and temperature lead to a single parameter, maturity, and accordingly, samples of the same concrete, whether in the cylinder or in the structure will be assumed to have acquired equal strengths provided they have equal maturities. The maturity method is an ASTM standard for in-place estimation of concrete strength (ASTM 1074). This technique is thoroughly described in the ASTM standard, and it will not be reiterated here. However, it suffices to explain that the practice for estimation of concrete strength by the maturity method involves determination of strength-maturity relationship from cylinder tests in the laboratory, measurement of concrete temperatures in the field, and estimation of in-place strength based on the laboratory established strength-maturity relationship. The fast track mix design and summary of results are given next.

MIX DESIGN

The scope of the study pertained to development of fast track mixes with cement types I and III. The following cement brands were employed:

1. Essroc types I and III.
2. Hurcules types I and III.
3. Lafarge types I and III.
4. Allentown types I and III.

The Blue Circle brand was also employed in a series of batches. However, these mixes did not yield fast-track results. The nominal mix constituents in one cubic yard of concrete in all mixes are given in Table 1.

Table 1. Mix design.

Cement	799 lbs.
Water	280 lbs.
w/c	0.35
Coarse Aggregate	1720 lbs.
Fine Aggregate	1110 lbs.
Hardening accelerator	45 oz /cwt
High Range Water Reducer	12 oz /cwt
Air Entraining Agent	1.2 oz /cwt

Mixing and batching operations were similar to the procedures involved in the previous study. Experimental results indicated that the combination of a hardening accelerator and proper initial mix temperature of 70^0 to 75^0F would achieve the required high early strength. Unlike a set accelerator, a hardening accelerator does not cause an early set of the concrete, but dramatically increases strength gain after concrete's initial set. Reactions pertaining to the accelerated gain in strength take place at temperatures within 70^0 to 75^0F. The mix contained a maximum coarse aggregate size of 1.5 inch. Gradation of the coarse and fine aggregates conformed to ASTM specification C33. The maximum amount of wash for coarse aggregates (passing sieve No. 200) was kept to less than 1.0 percent. Quality control tests were performed in order to assure the maximum amount of moisture absorption to be confined to less than 0.6 for coarse and 1.5 % for fine aggregates respectively. They are reiterated in the following for completeness:

Batching, and Testing Procedures:

1. Adjust mix design for moisture content of sand and stone.
2. Add air entraining agent to fine aggregate.
3. Add coarse aggregates.
4. Add $\frac{2}{3}$ of batch water.
5. Add HRWR.
6. Add the remaining batch water and mix for 3 minutes.
7. Addition of the hardening accelerator is dependent on the ambient temperature and truck travel time between the plant and the job site. When ambient temperatures are above 80^0F, it is recommended that the accelerating admixture to be added at the job site. At temperatures below 80^0F or for anticipated travel times less than 30 minutes, the accelerating admixture can be either added at the batch plant or at the point of placement. Actual field trials shall be performed for precise timing in terms of addition of the accelerator to the mix.
8. Mix the concrete for about five minutes following the addition of the hardening accelerator.
9. Run the standard tests,i.e. slump, air content, temperature etc.
10. The temperature of the concrete should be above (70^0F) when delivered at the point of placement.

11. Thermal blankets are to be used to cover the slab as soon as the concrete is finished.
12. 4 × 8 inch cylinders are prepared, sealed and kept in a protected chamber.
13. Thermocouples are placed in the slabs for measurement of maturity. At least two thermocouples shall be placed not more than an inch away from a corner near roadway shoulder, one of which at two inches from the bottom , and the other at about two inches from the top of the slab. The maturity of the slab as measured from the thermocouple indicated lower temperatures were taken as the governing maturity of the pavement.
14. Maturity correlation relationships need to be developed in the laboratory for each mix prior to field application.

RESULTS

Properties of the fast-track concrete in fresh state (slump, % air) as well as in the very early ages (strength) are given in Table 2. SK8, and VHE-2 mixes in this table pertain to the previous study (Essroc cement), and are given for reference. In this table, H1, E1, Laf1, AL1 refer to concretes made with Hercules, Essroc, Lafarge, and Allentown type I cements. H3, E3, Laf3, and AL3 refer to concrete mixes made with type III cements. All the cements tested achieved the required compressive strength ($f_c^{'}$) within the first 6 to 7 hours after mixing. As indicated in table 2, experiments were repeated until the mix achieved the required strength. Time needed to achieve a flexural strength (f_b) of 350 psi is also given in table 2.

For each cement brand and type a control mix (0 oz of hardening accelerator) was also prepared for comparison. Results for those mixes are also given in table 2. On the average, the air content of the fresh mixes ranged between 3.5 to 7 percent. In most mixes, a nominal air content of 5 percent was achieved. Slumps varied widely, however, all mixes including those with lower slump values were thoroughly workable. In general, the fast-track mixes possessed good rheological properties.

Table 2 Early age properties of fast-track concrete.

Experiment	5 hr. fc’ (psi)	6 hr. fc’ (psi)	7 hr. fc’ (psi)	Hrs. to > 350 psi fb’	Initial Slump (inches)	Air Content %
SK8 (E799 32 oz)	472	2145	2205	6.05	9.5	5.0
VHE-2 705#	2652	1114		5.08	4.75	5.2
VHE-2 799#	1512	2407	3075	6.0	6.25	5.0
H1-1	400	1723	3727	6.58	3.0	4.5
H1-2	600	1514	3110	6.33	5.5	4.5
H1-3	122	317	1674	7.33	5.5	5.0
Lafl-1	239	336	1610	7.87	4.0	
Lafl-2	2000	2710	2813	5.67	5.5	
Lafl-3	1300	2565		5.67	5.0	4.2
Lafl-4	711	2100	2562	7.0	4.5	5.0
Lafl-5 (0 oz)	247	868	1455	9.16	5.75	6.0
AL1-1	500	1688	2781	6.41	5.25	5.25
AL1-2	300	1237	2900	7.0	4.0	4.9
E1-1	163	463	2287	7.5	7.5	6.5
E1C (0 oz)		168	415	12.0	-	-
E1-2 (32 oz)	300	1603		6.5	5.0	5.8
E1-2A (20 oz)		600	1962	7.5	-	-
L3-2C (12 oz)		208	1670	8.5	-	-
L3-1 (20 oz)	101	418	2290	7.41	5.5	3.5
L3-2 (28 oz)		1742	2218	7.16	3.5	3.5
L3-3 (36 oz)	1267	2390		6.83	3	
H3-1C (0 oz)		202	1195	9.5	-	-
H3-1 (36 oz)	230	2246		6.33	4.5	5.0
H3-2	414	2136		6.25	4.5	4.2
H3-2A (36 oz)		388	2403	7.0	-	-
H3-3	500*	2436		5.91	2.75	4.9
H3-3 (50 oz)	1739	2730		5.58	-	-
AL3-1 (0 oz)	1137	2290		6.0		
AL3-1C (36 oz)	3010			4.83	6.5	5.0
AL3-2	720	2851		5.5	6.5	4.3
ES3-1 (36)		745	2980	6.5	7.25	7
ES3-1C (0 oz)		352	1346	10.5		
ES3-2 (w/c=0.45)		216	1020	8.25	8.75	3.8
ES3-2C (20 oz)		206	971	8.25		

Mixes contain 45 oz /cwt Rapid1 except where noted

* Intorpolated Values

The compressive strength development of concrete mixes produced by type-I cements are shown in Figs. 1 through 4. As per ASTM requirements, every single data point in these figures represents the average compressive strength of at least two cylinders. These results indicate that all the mixes easily surpassed the 2500-psi strength level 6 to 7 hours after mixing operations. Results from all of the type-I cement mixes are compared in Fig. 5. As shown in this figure, even in worst cases, the concrete gained about 3000 psi in 7 hours. In am similar fashion, the strength versus maturity curves for type-I Portland cement concretes are shown in figures 6 through 9. Comparison results indicate that in the majority of cases, the fast-track concrete reaches the target strength at a maturity of about 130 deg.-C-hours. However, in few cases, this number increases to 150 deg.-C-hours. Therefore, for type-I cement fast-track concrete, it will be safe to assume full strength development at maturity of 150 (Fig.10).

Figures 11 through 14 represent the early age development of fast-track concrete made with type-III Portland cement. Furthermore, results from the four different cement brands are compared in Fig. 15. In summary, all the cements surpassed the required strengths within the first 7 hours of their age. Comparison of type-I and type-III strength-time results indicates that the type-III mixtures attained larger strengths than their type-I counterparts within the first 7 hours. Strength versus maturity curves for type-III mixtures are shown in Figs. 16 through 20. Maturity results for type-III concretes indicated that except for the mixes produced by Lafarge cements, all the concretes attained the required strengths at maturities between 130 to 150 deg.-C-hours. These results are in consonance with those obtained with type-I cements. In summary, as a practical rule of thumb the following rule will apply to field fast-track concretes irrespective of cement brand and type:

At a maturity of 150 deg-C-hours a fast-track concrete will achieve a compressive strength beyond 2250 psi

In fig. 21, the modulus of rupture data are plotted against compressive strength. As expected large scatter does not permit develoment of a definitive relationship between the strengths. However, early age data indicates that in most cases, the required compressive and flexural strengths are achieved within the same time-period.

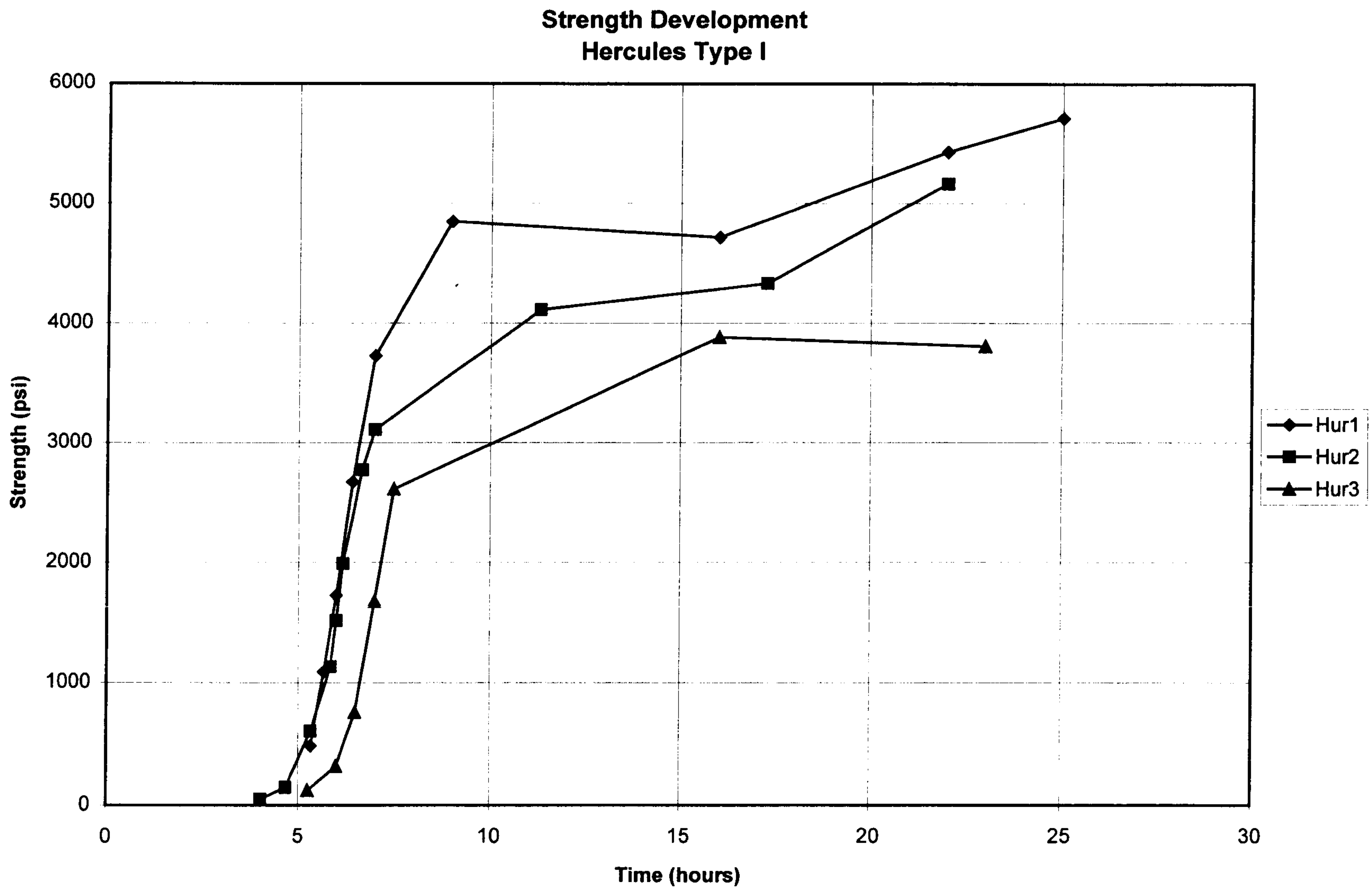

Fig.1 Strength time relationship for type-I cement.

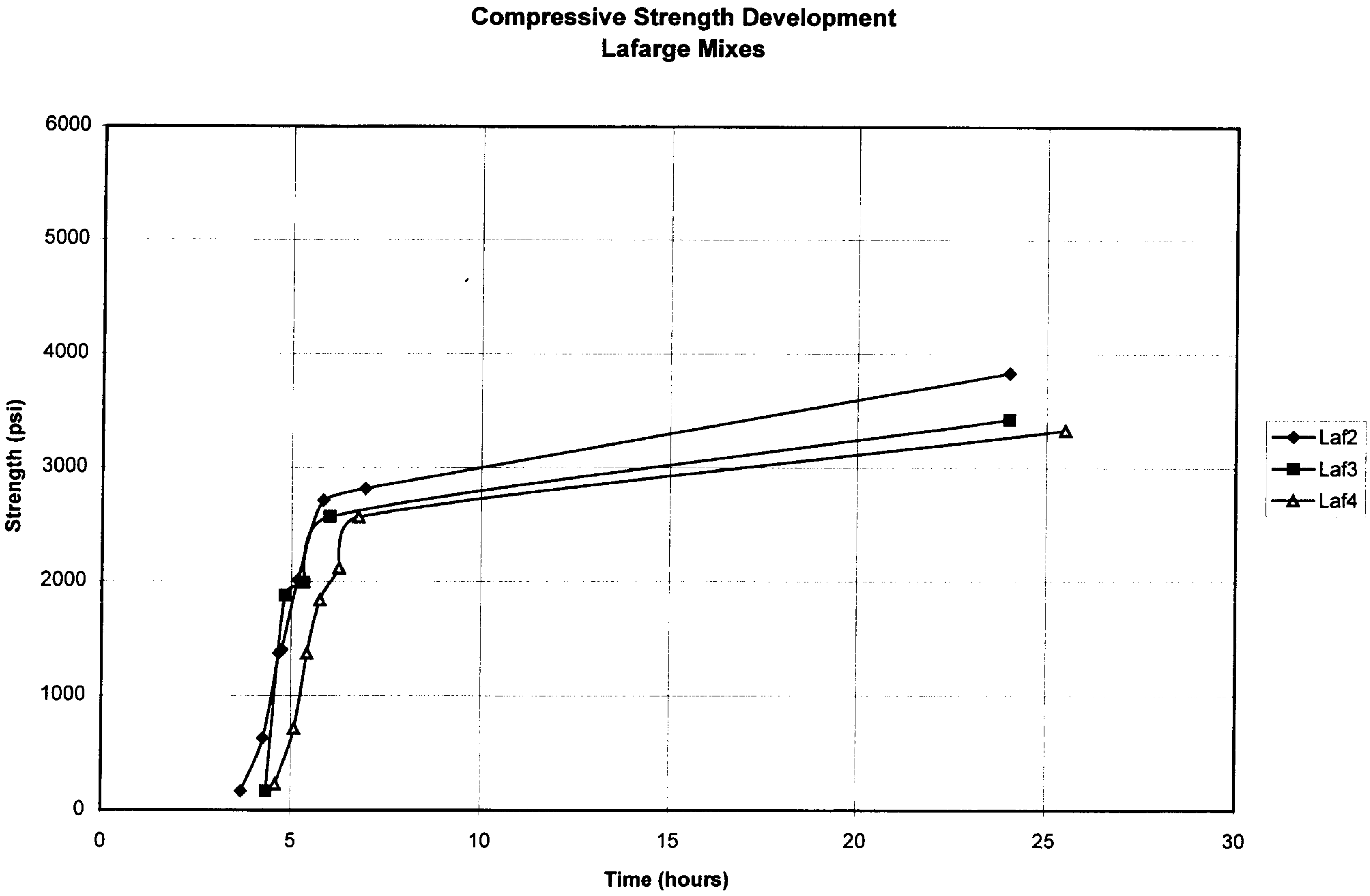

Fig.2 Strength time relationship for type-I cement.

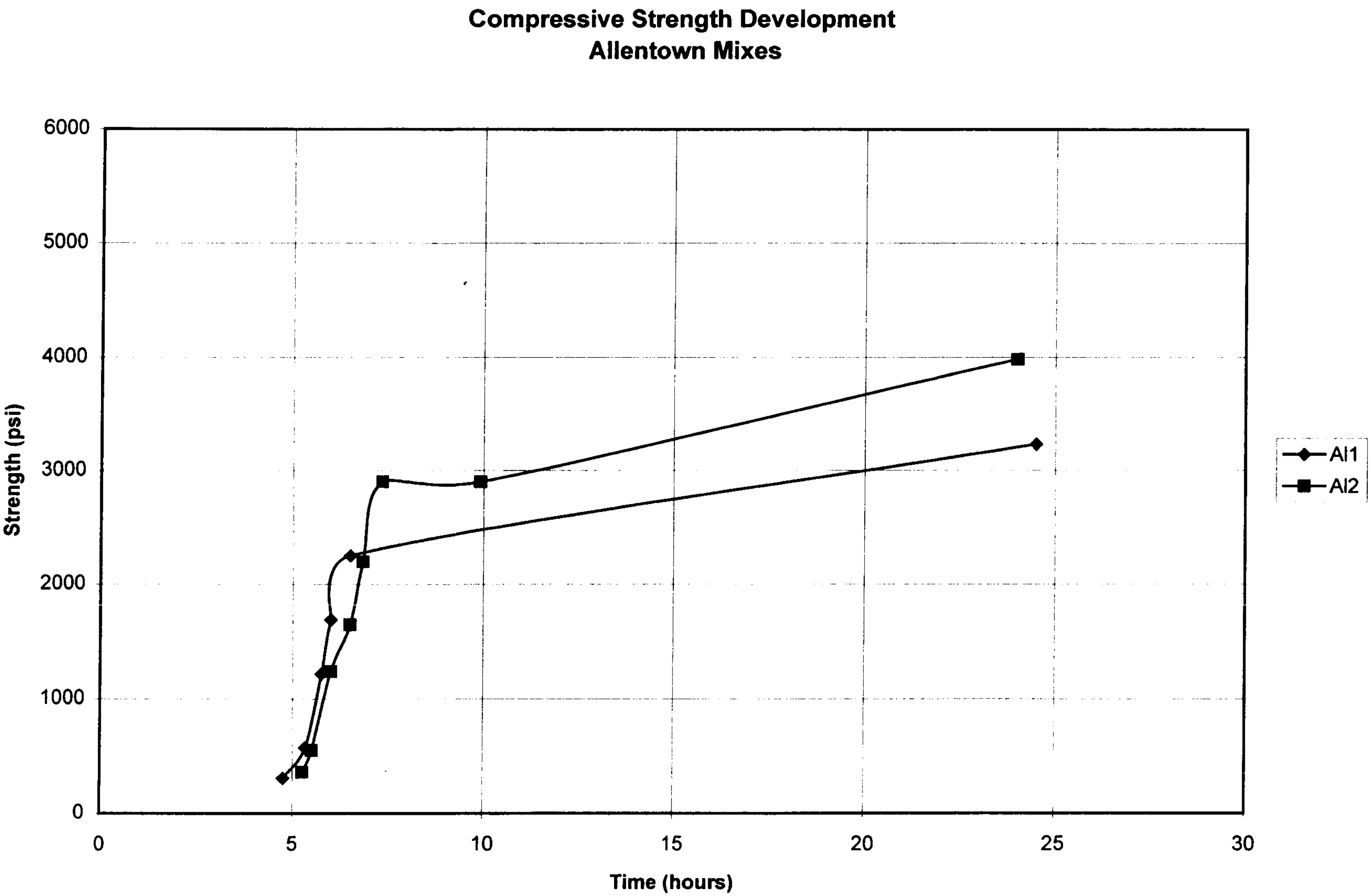

Fig.3 Strength time relationship for type-I cement.

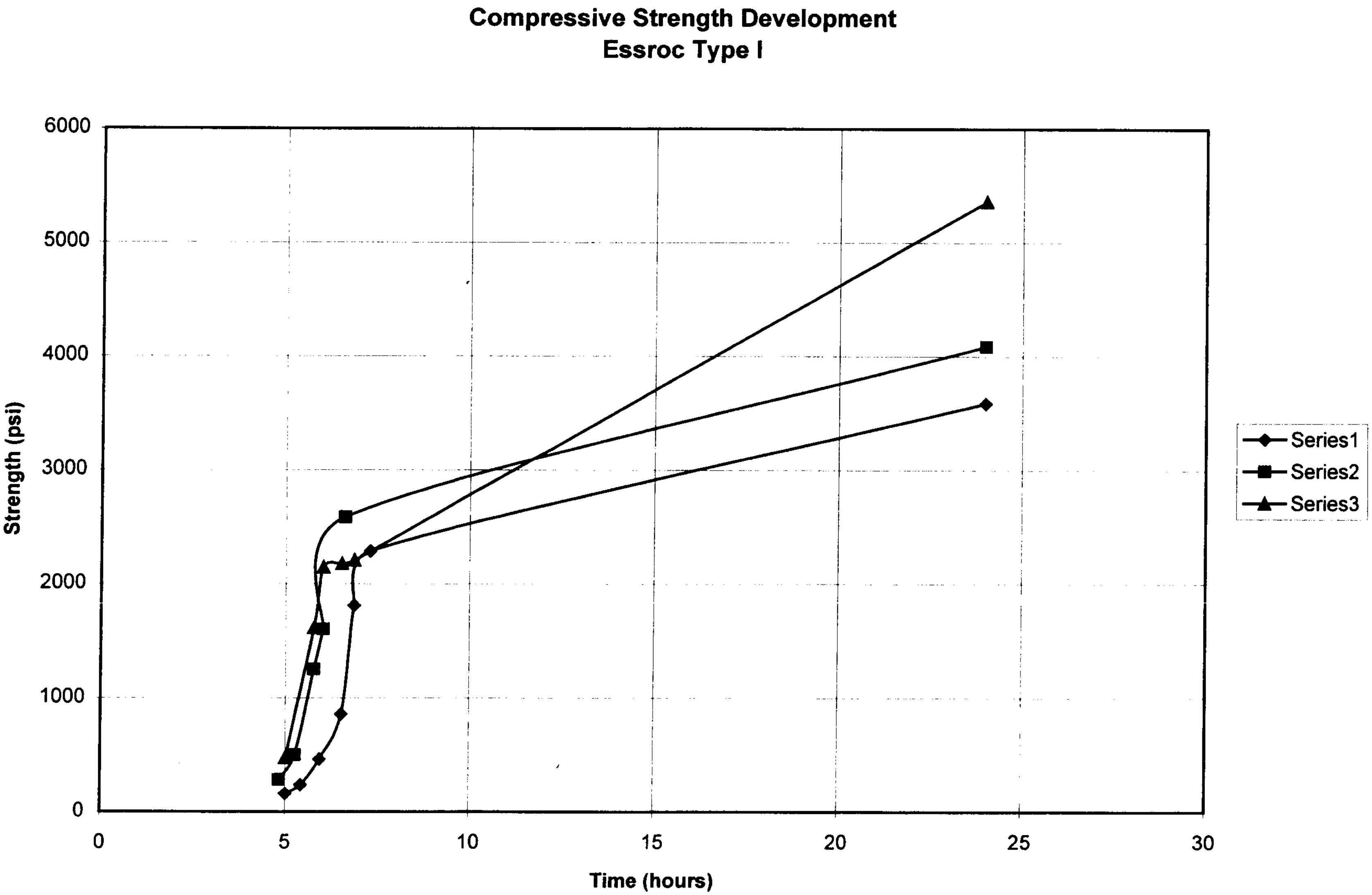

Fig.4 Strength time relationship for type-I cement.

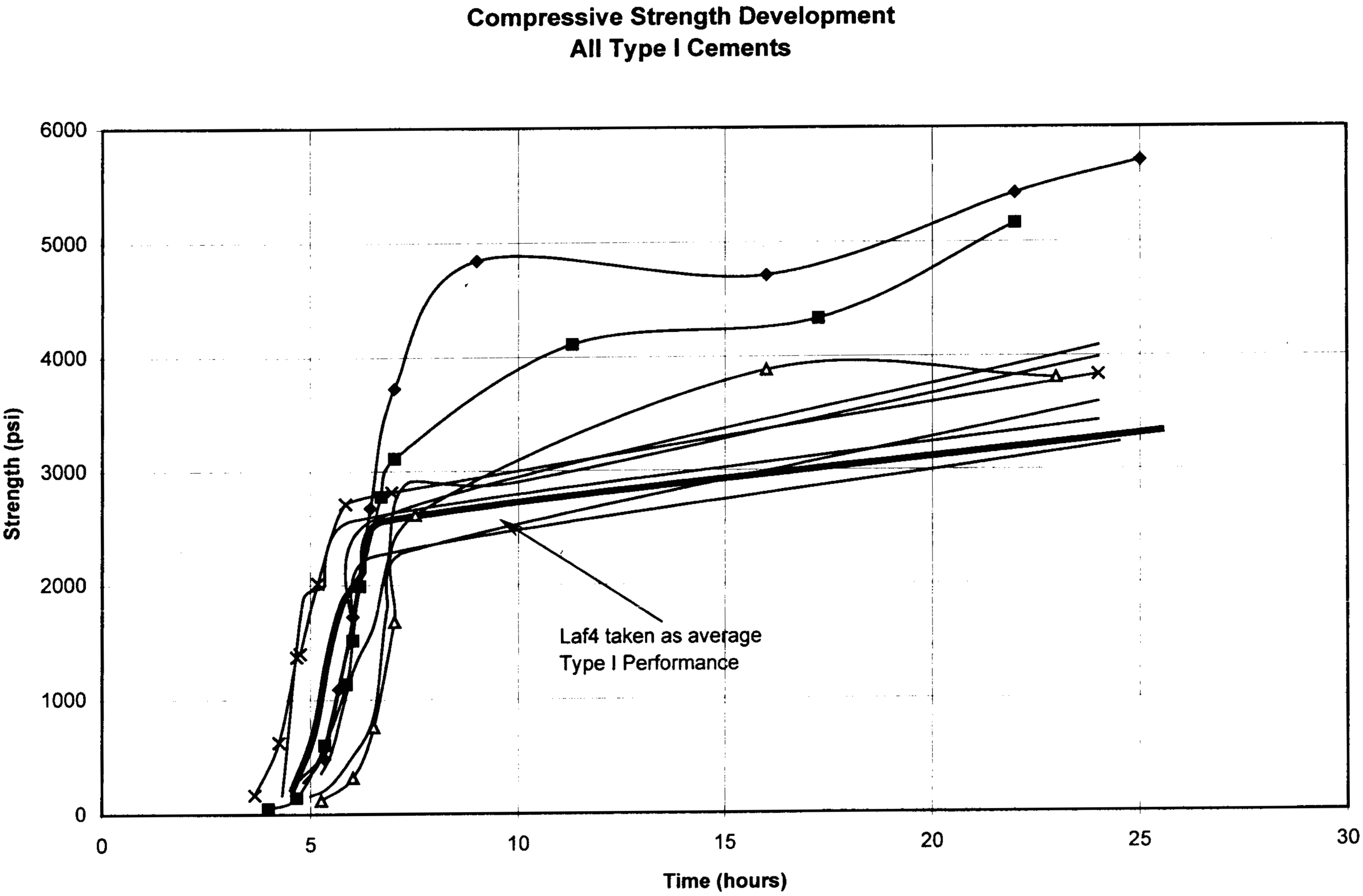

Fig.5 Strength time relationship for all type-I cements.

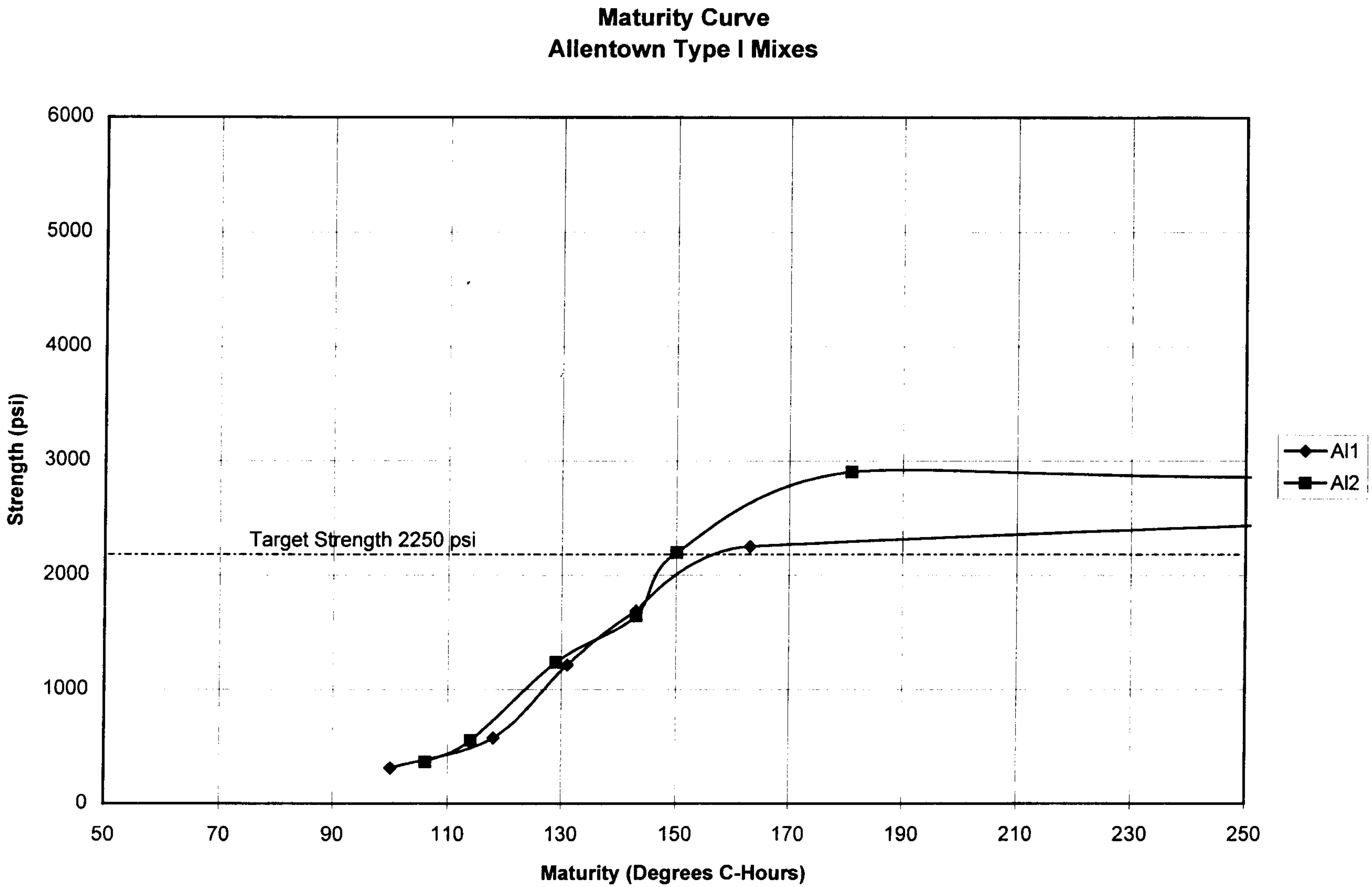

Fig.6 Strength maturity curve for type-I cement.

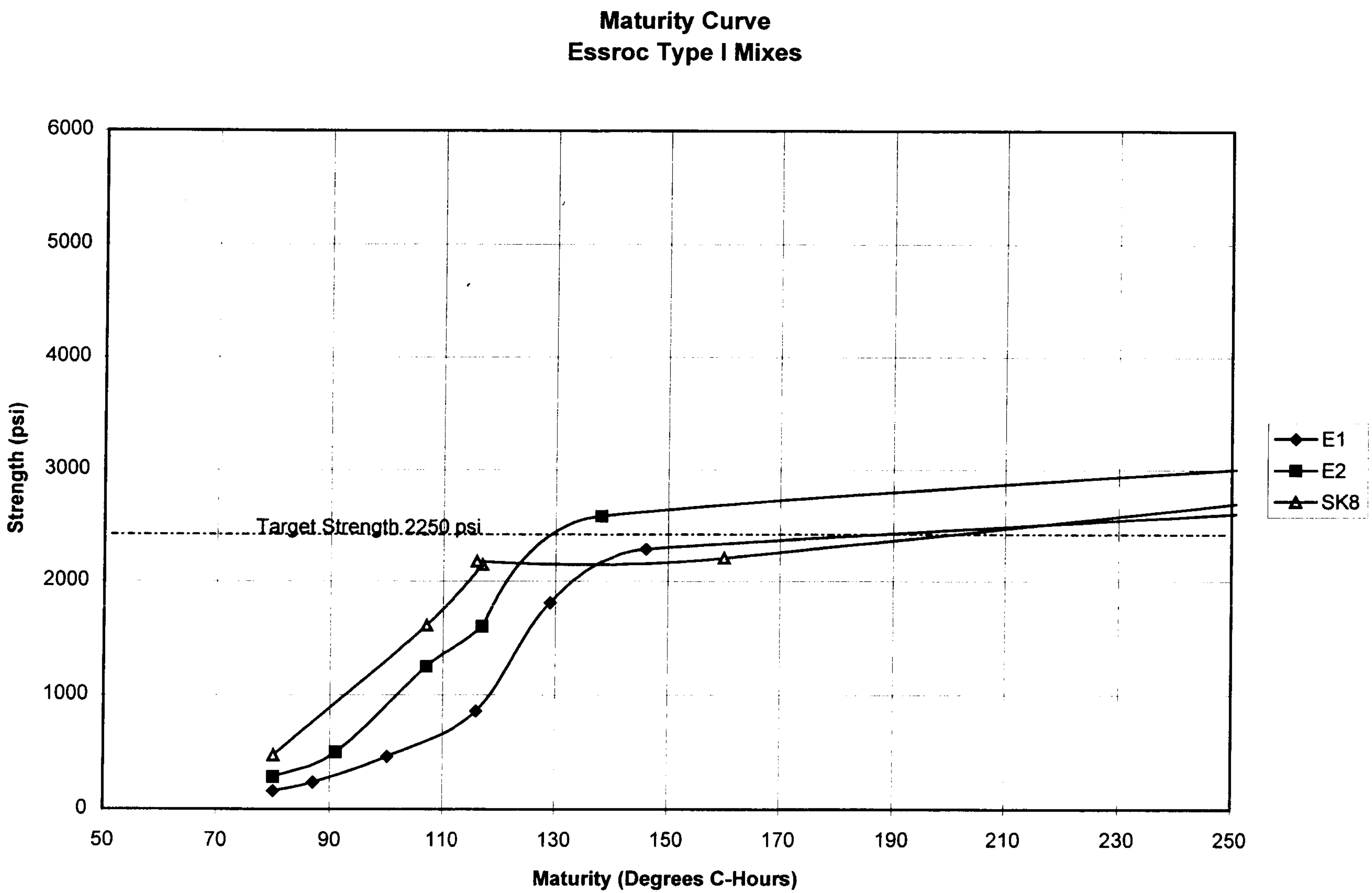

Fig.7 Strength maturity curve for type-I cement.

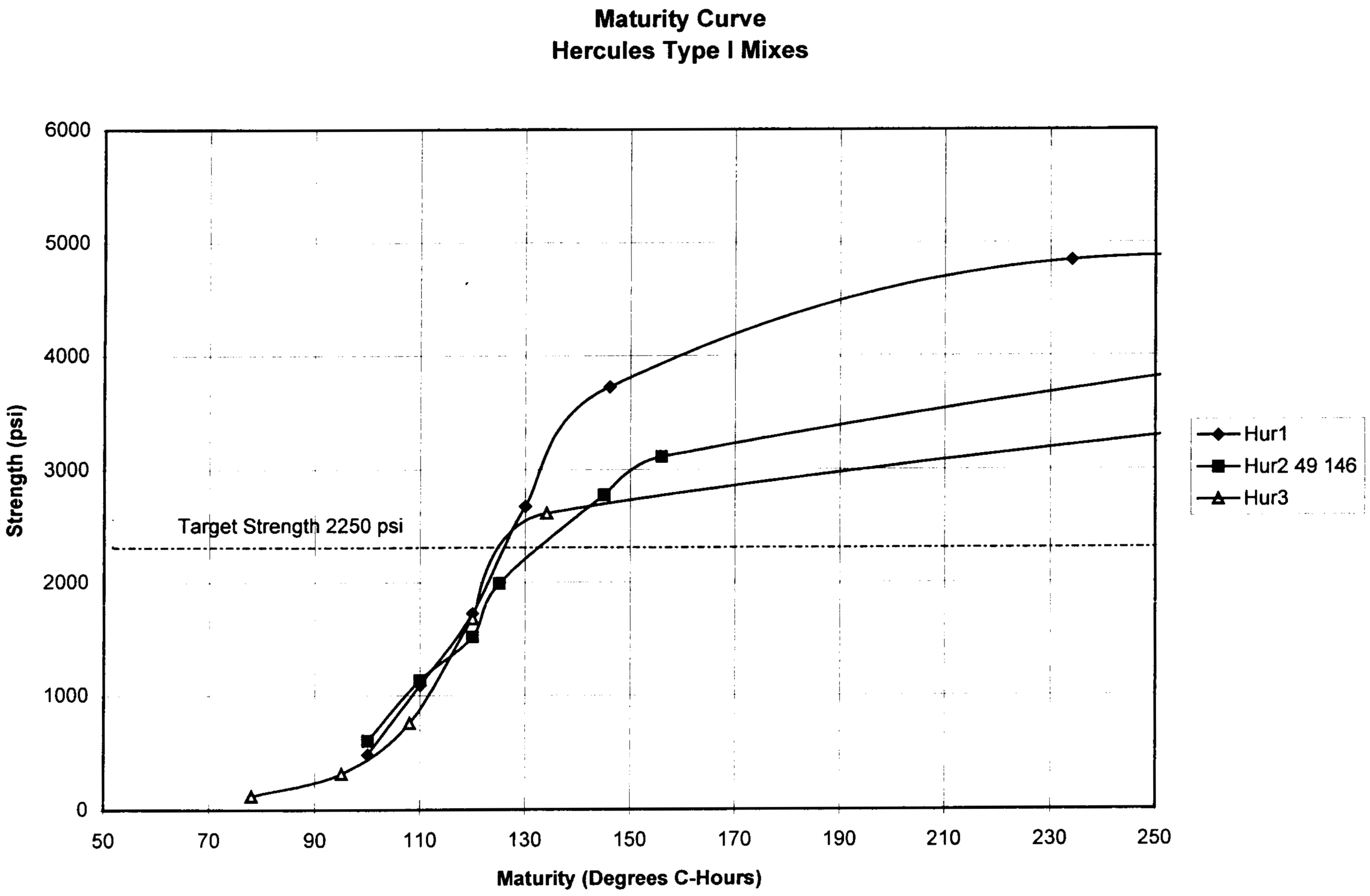

Fig.8 Strength maturity curve for type-I cement.

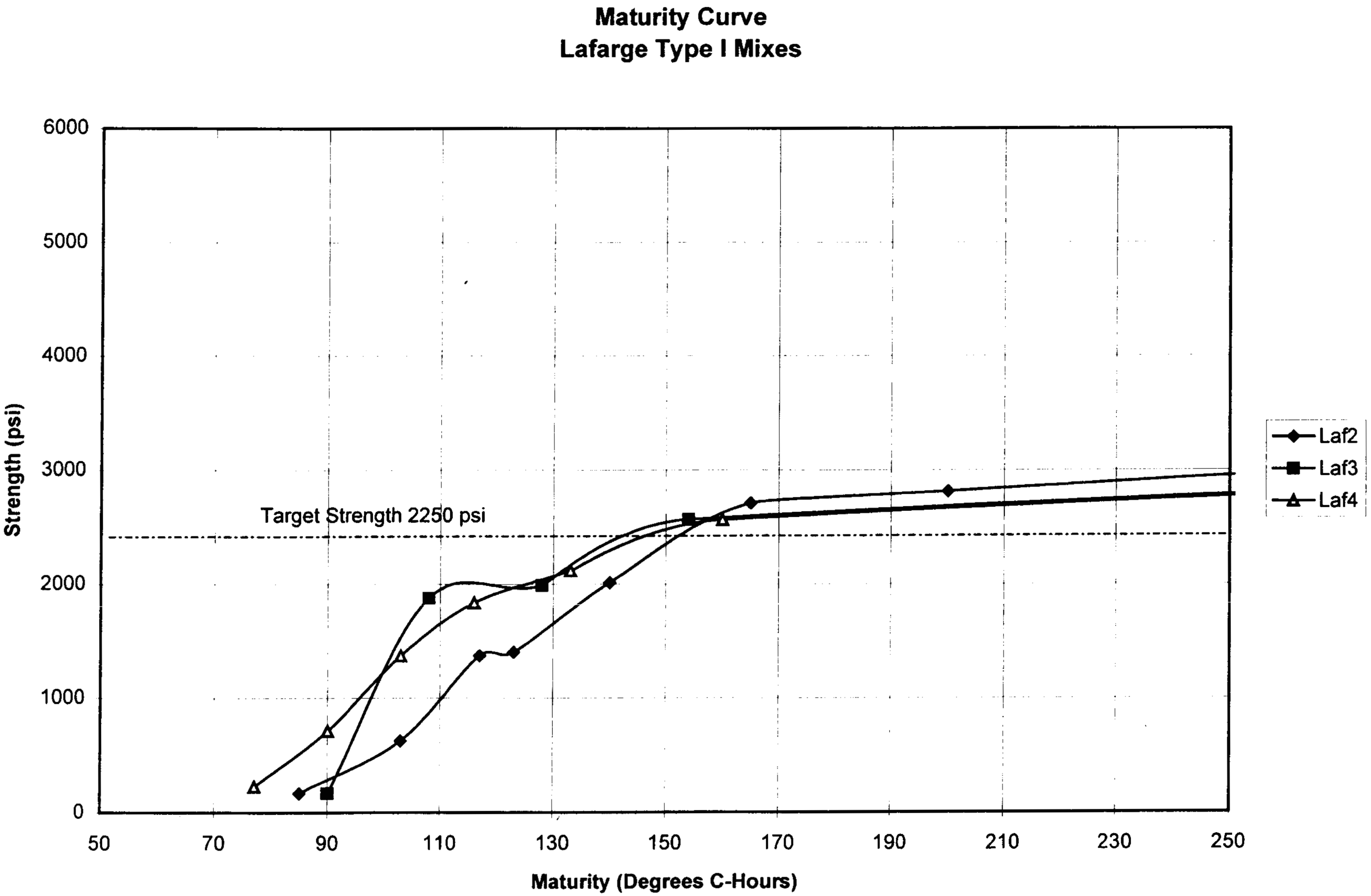

Fig.9 Strength maturity curve for type-I cement.

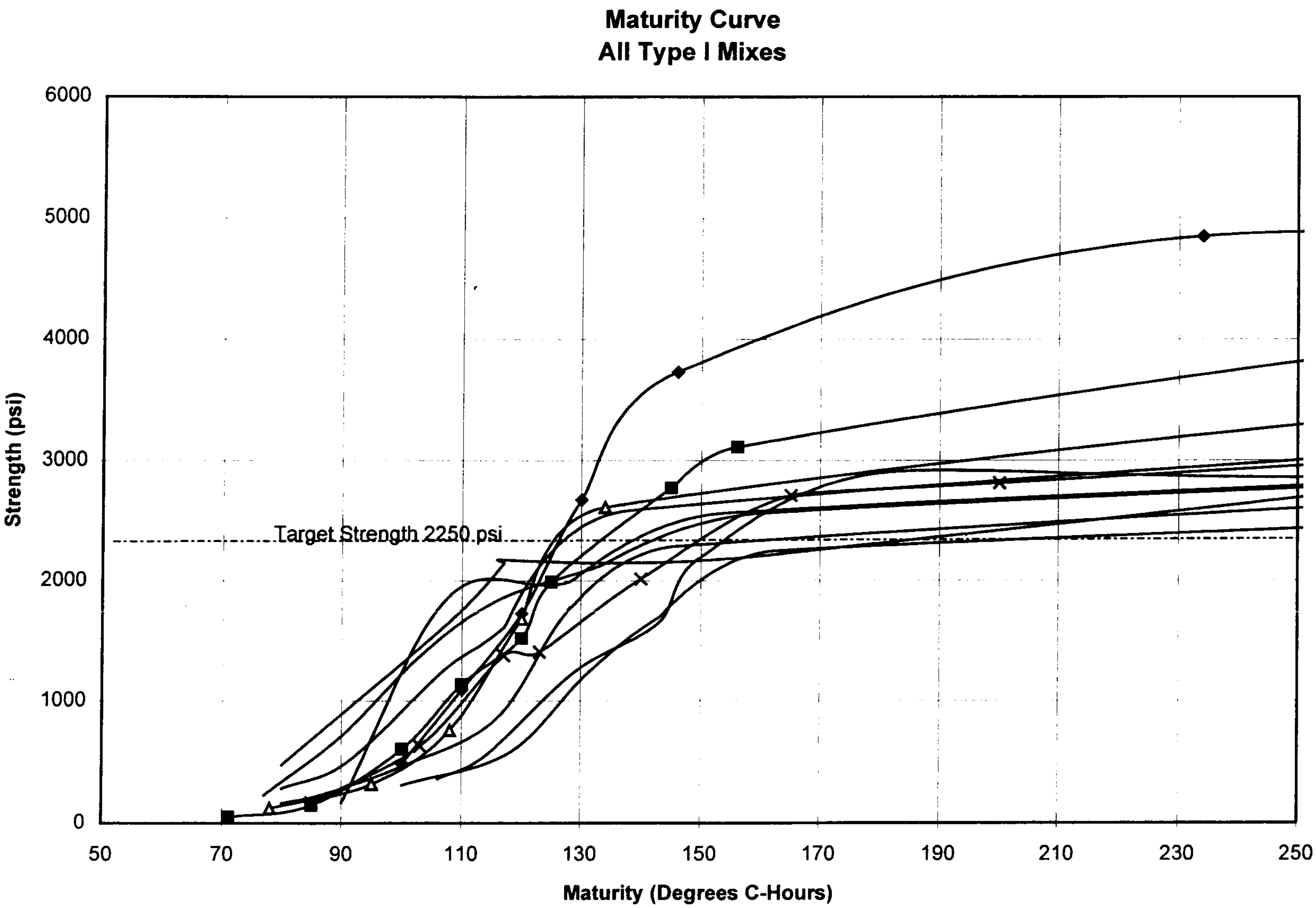

Fig.10 Strength maturity curve for all type-I cement.

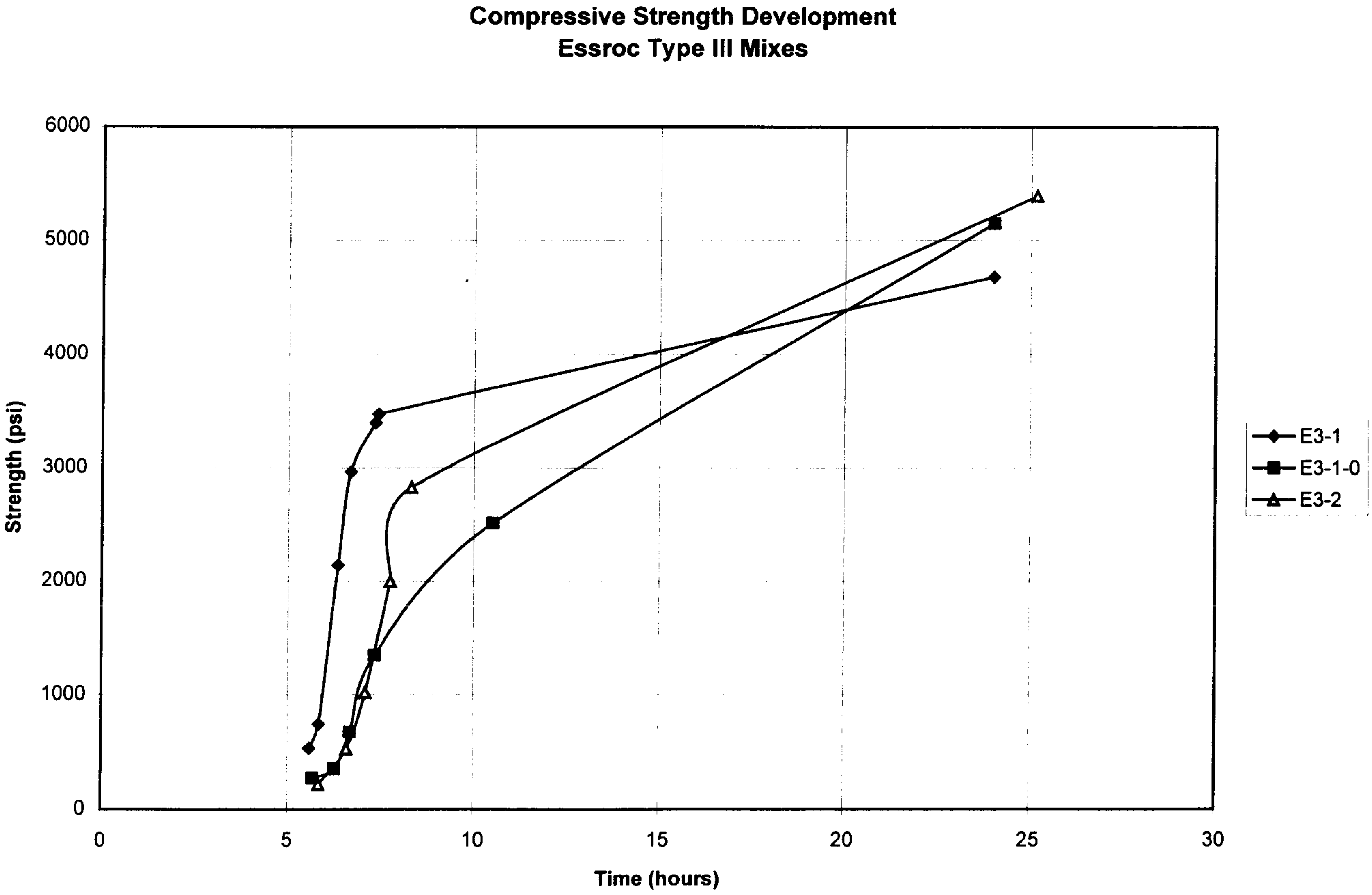

Fig.11 Strength time relationship for type-III cement.

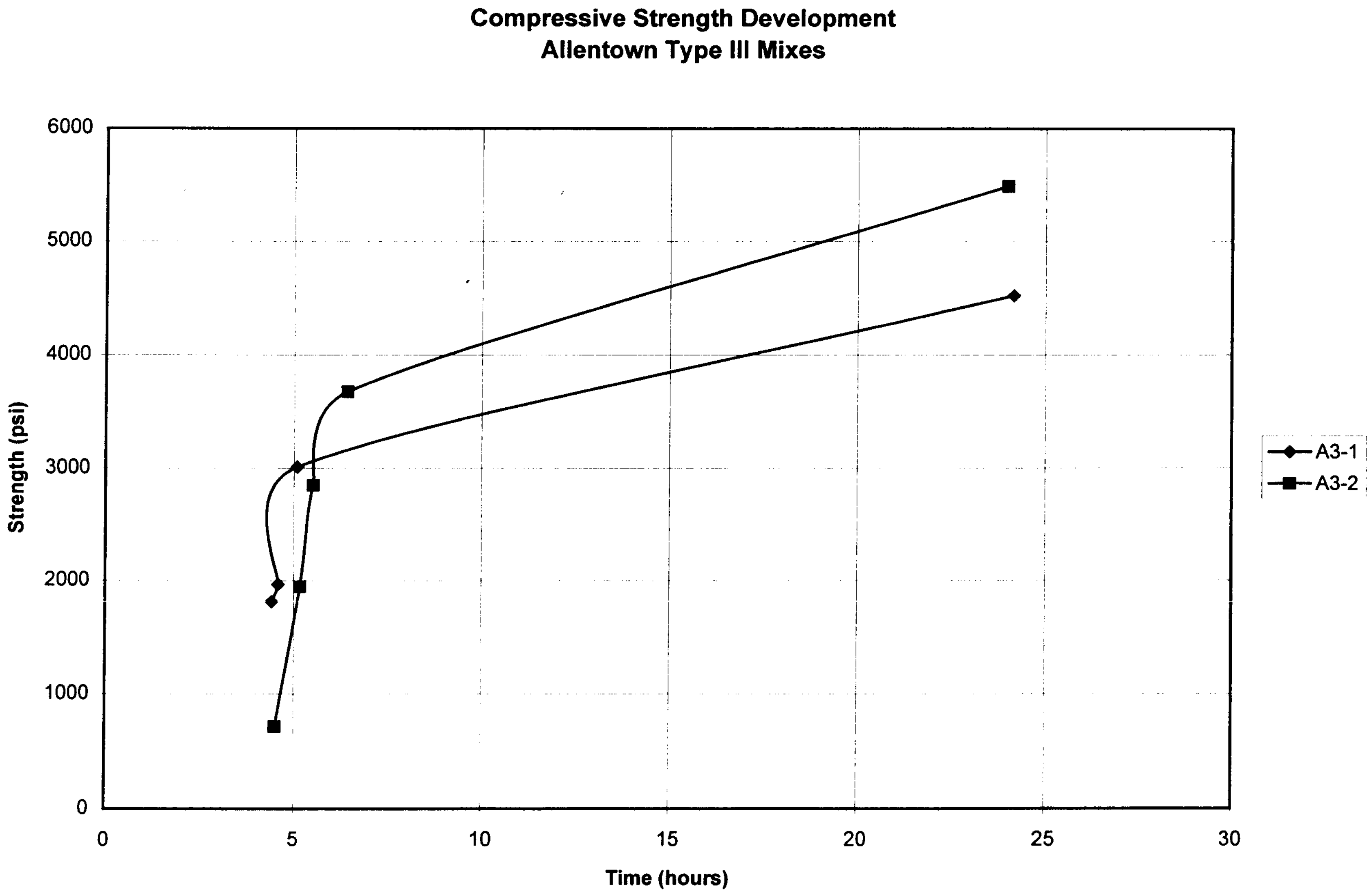

Fig.12 Strength time relationship for type-III cement.

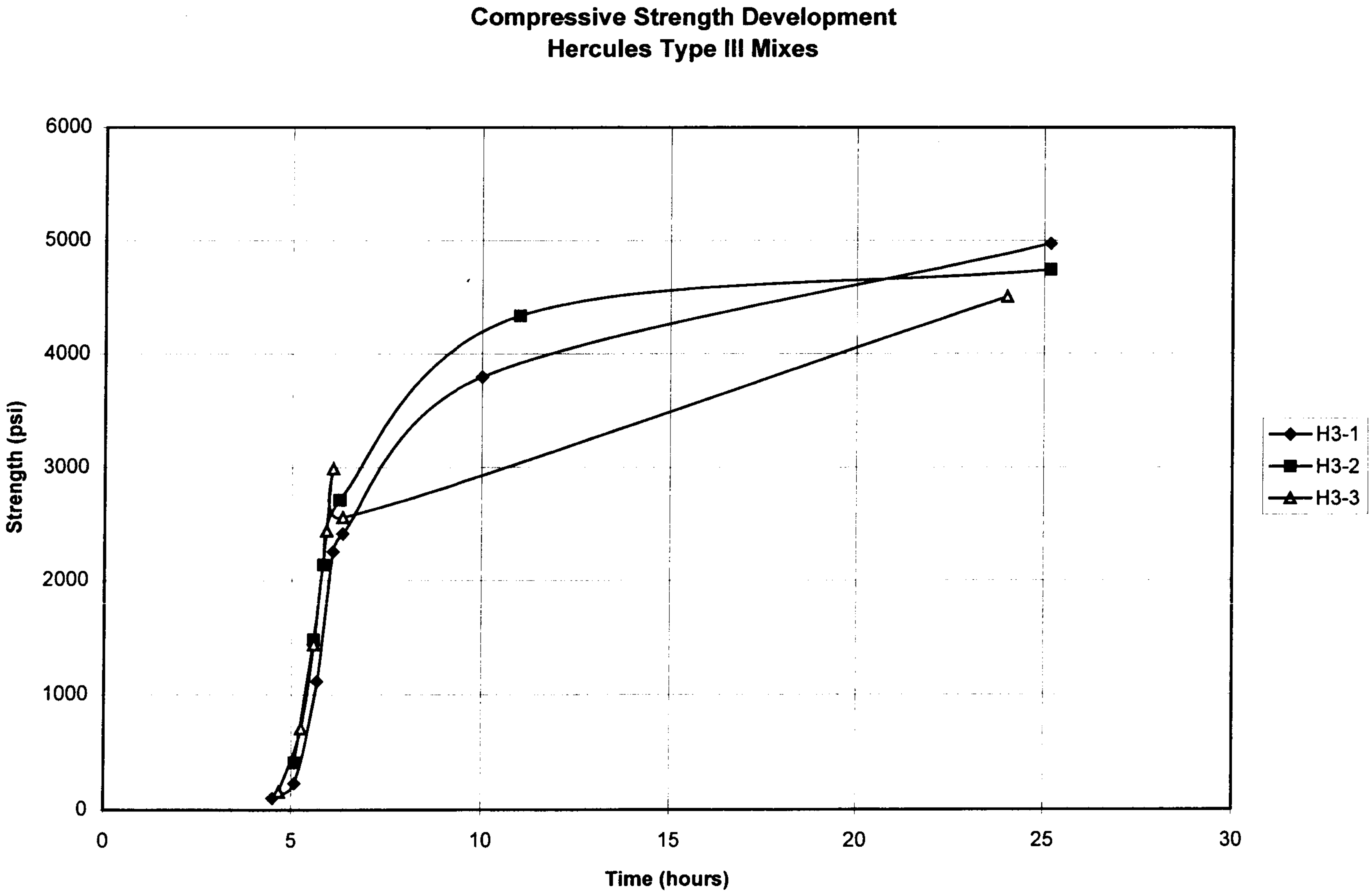

Fig.13 Strength time relationship for type-III cement.

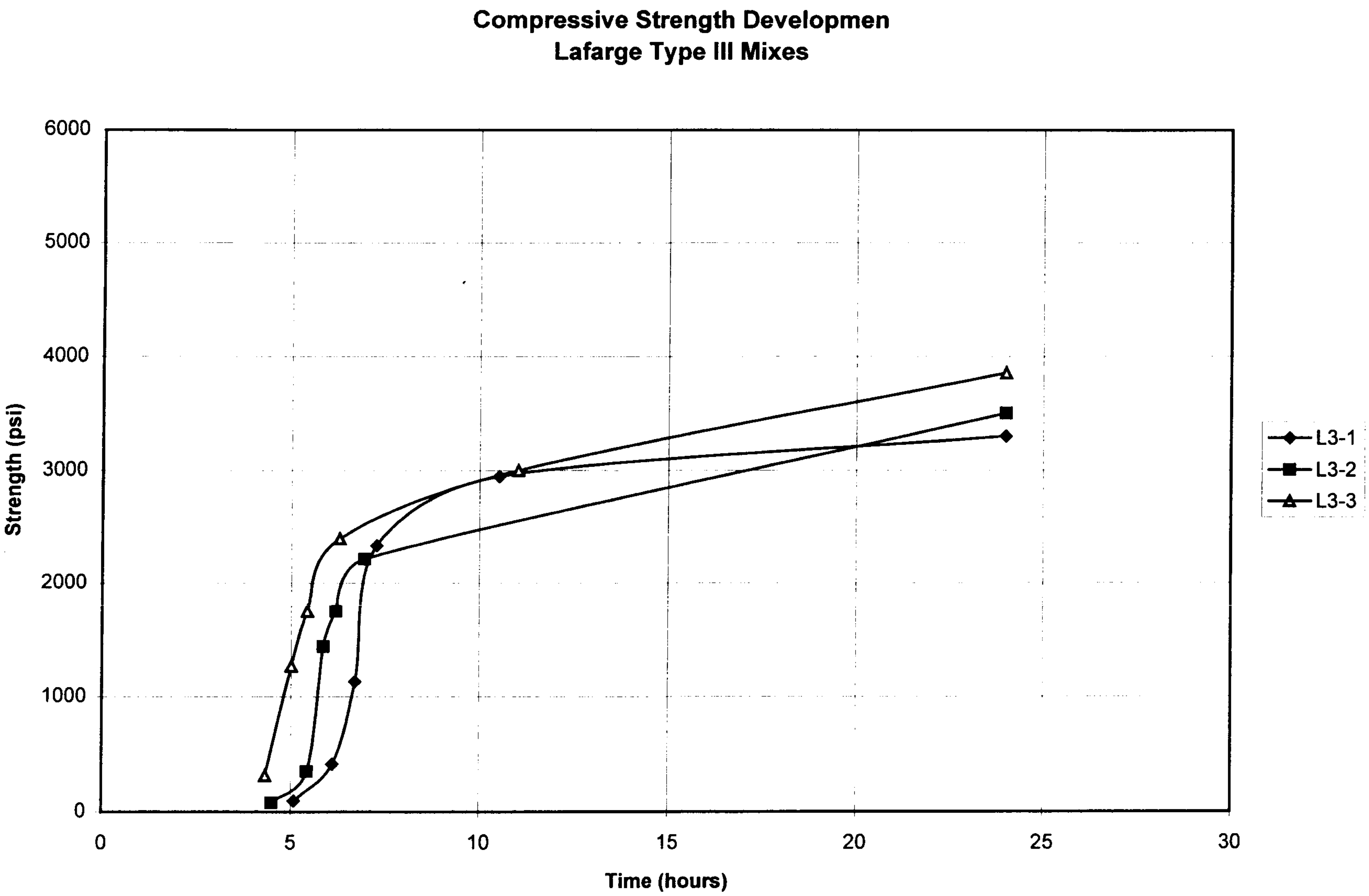

Fig.14 Strength time relationship for type-III cement.

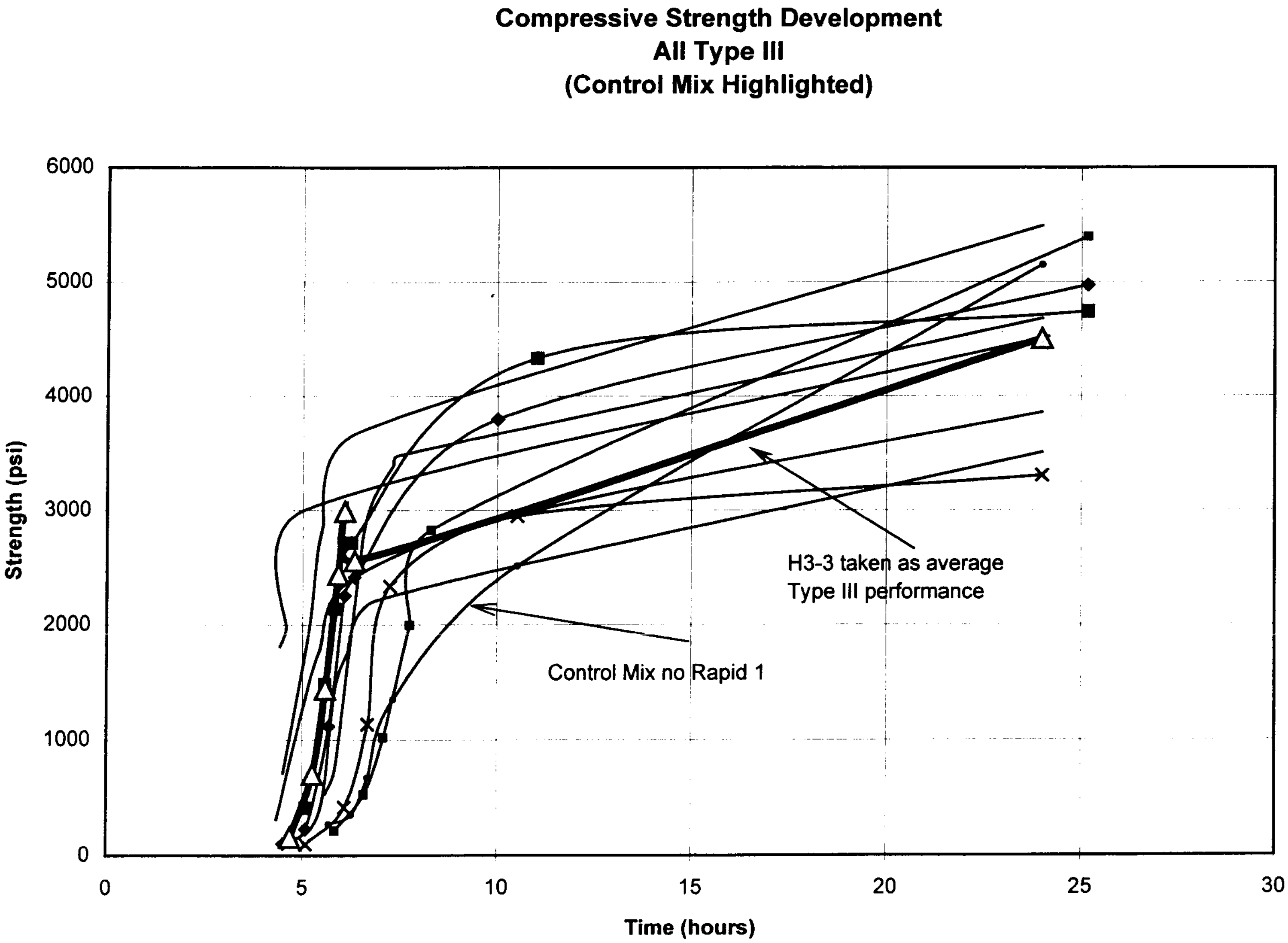

Fig.15 Strength time relationship for all type-III cement.

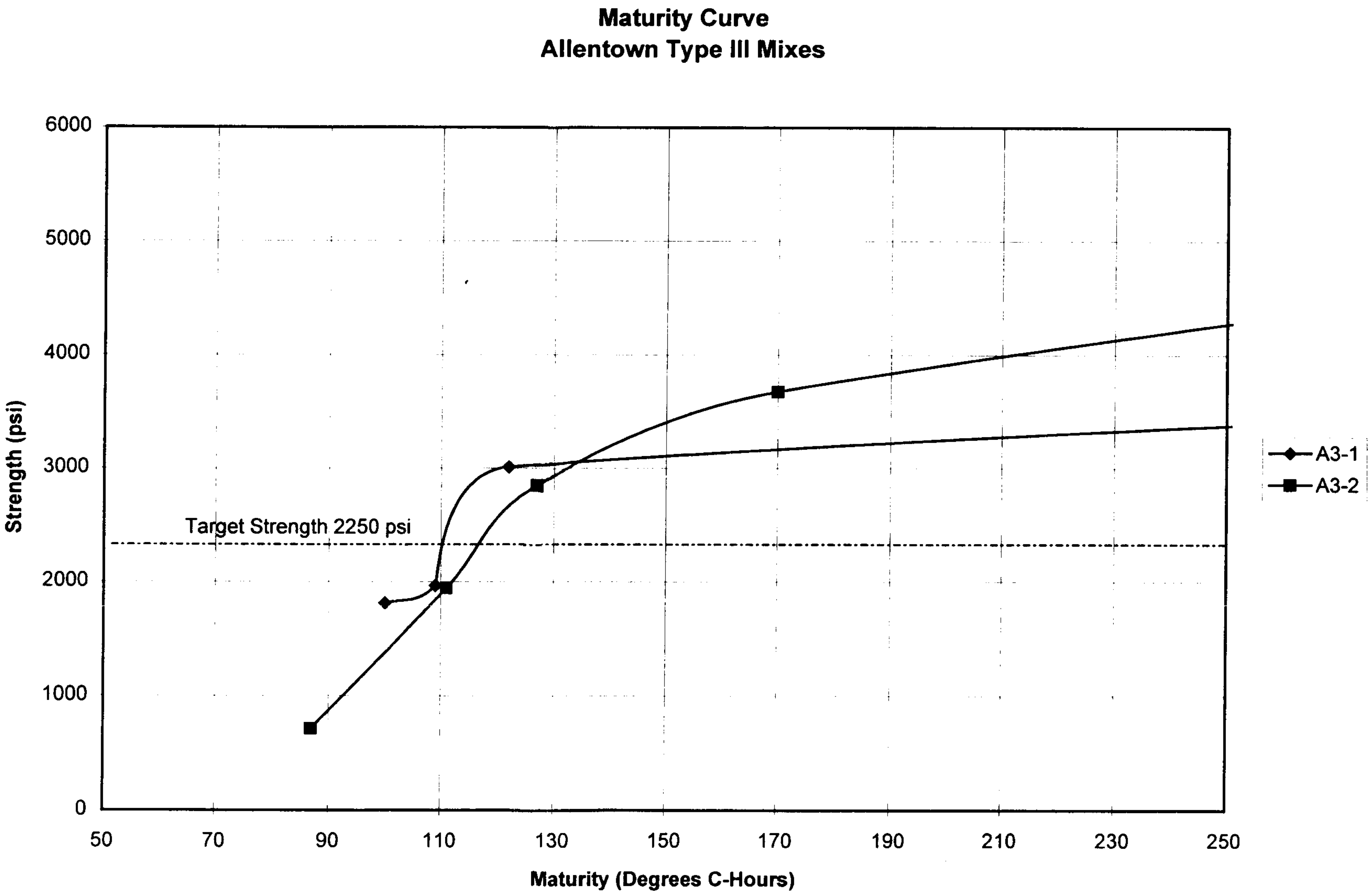

Fig.16 Strength maturity curve for type-III cement.

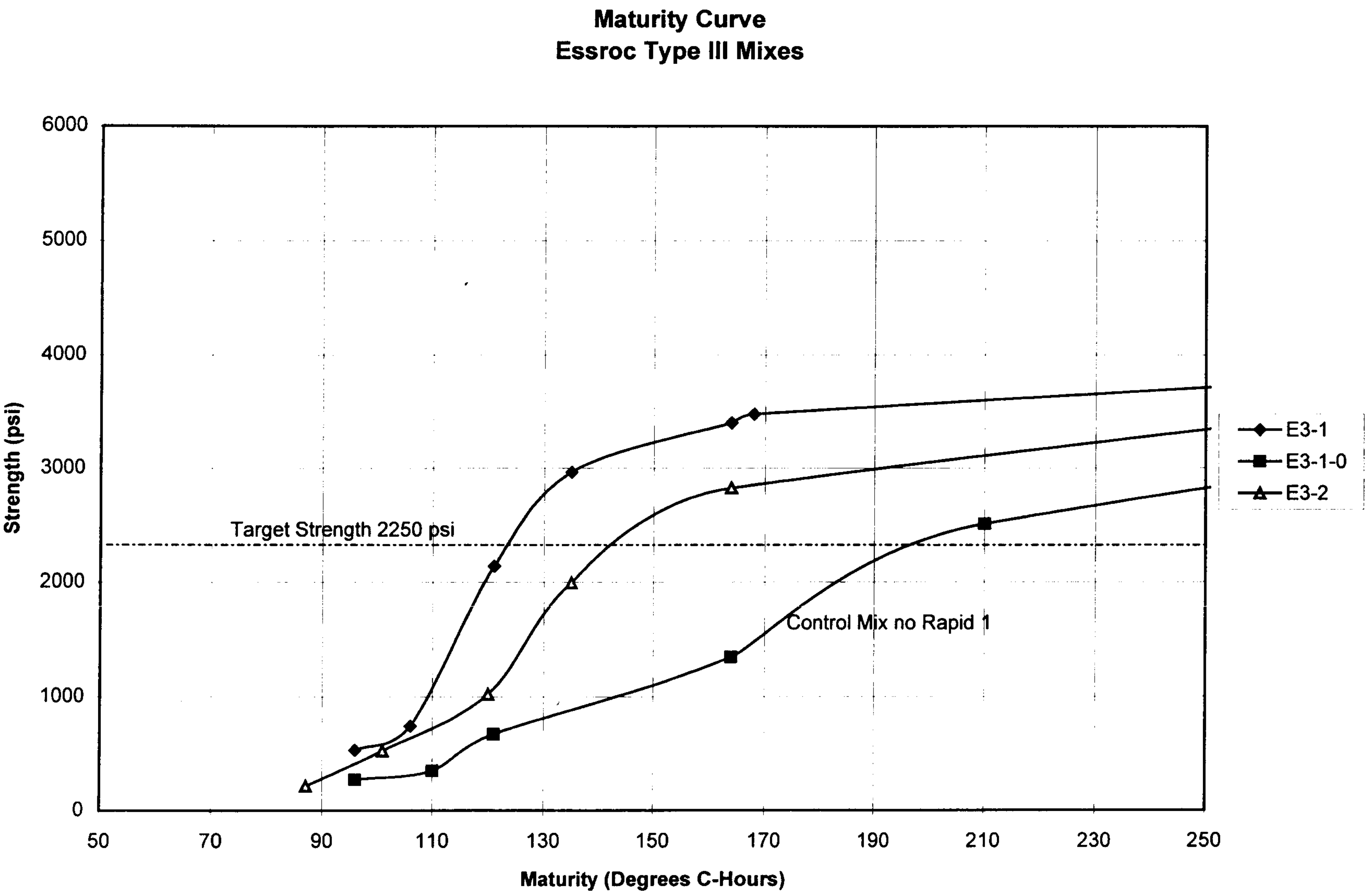

Fig.17 Strength maturity curve for type-III cement.

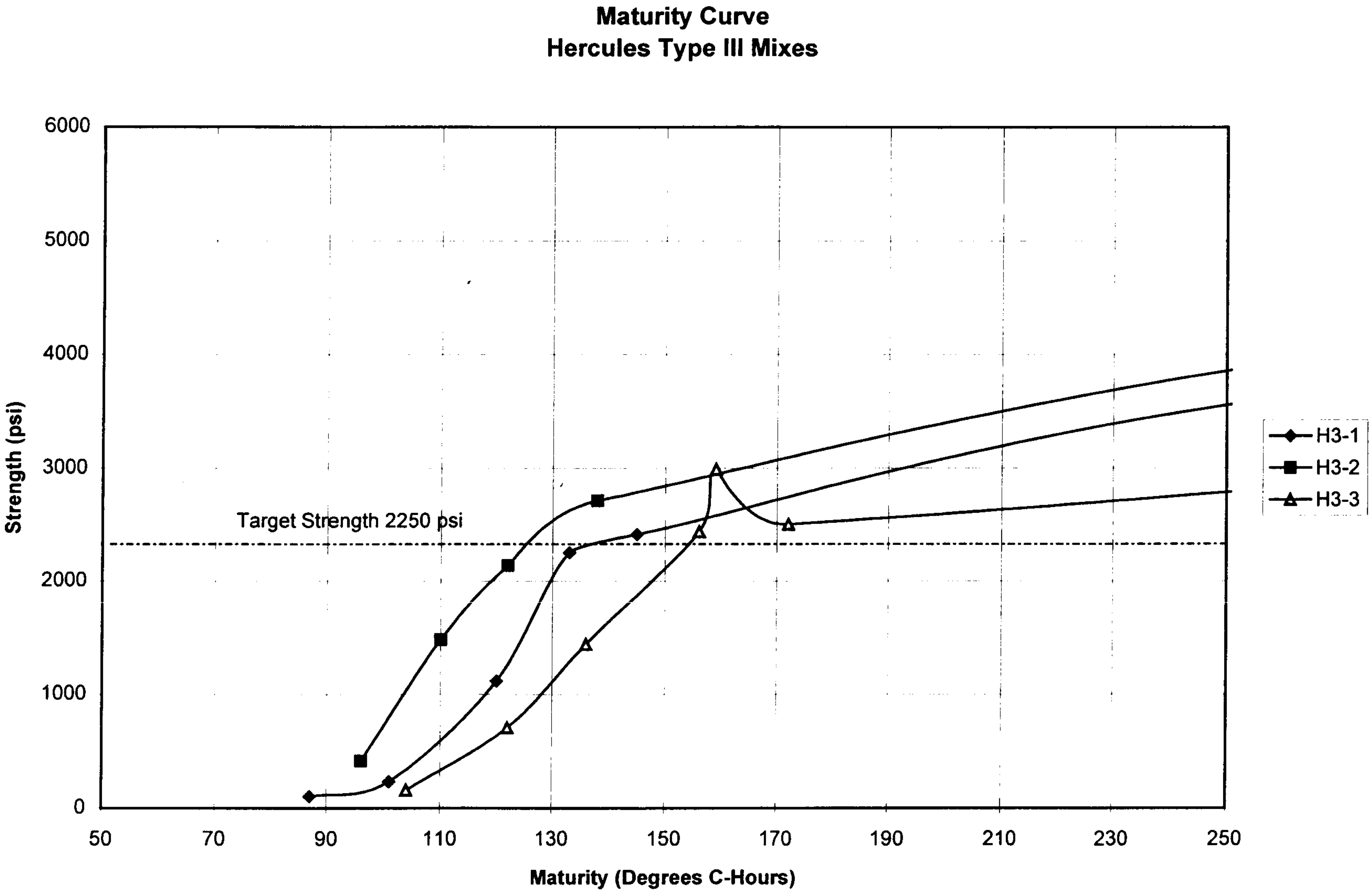

Fig.18 Strength maturity curve for type-III cement.

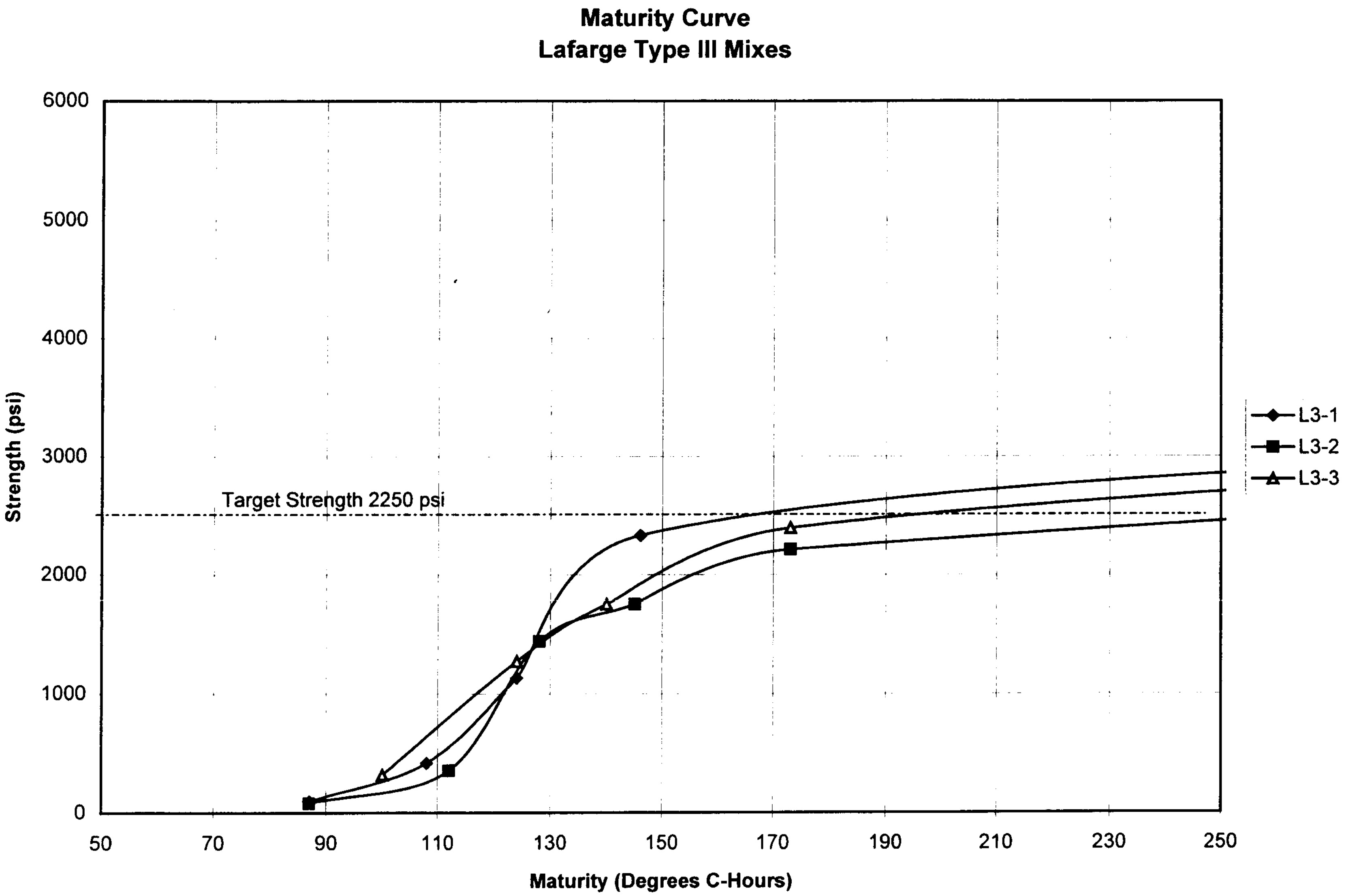

Fig.19 Strength maturity curve for type-III cement.

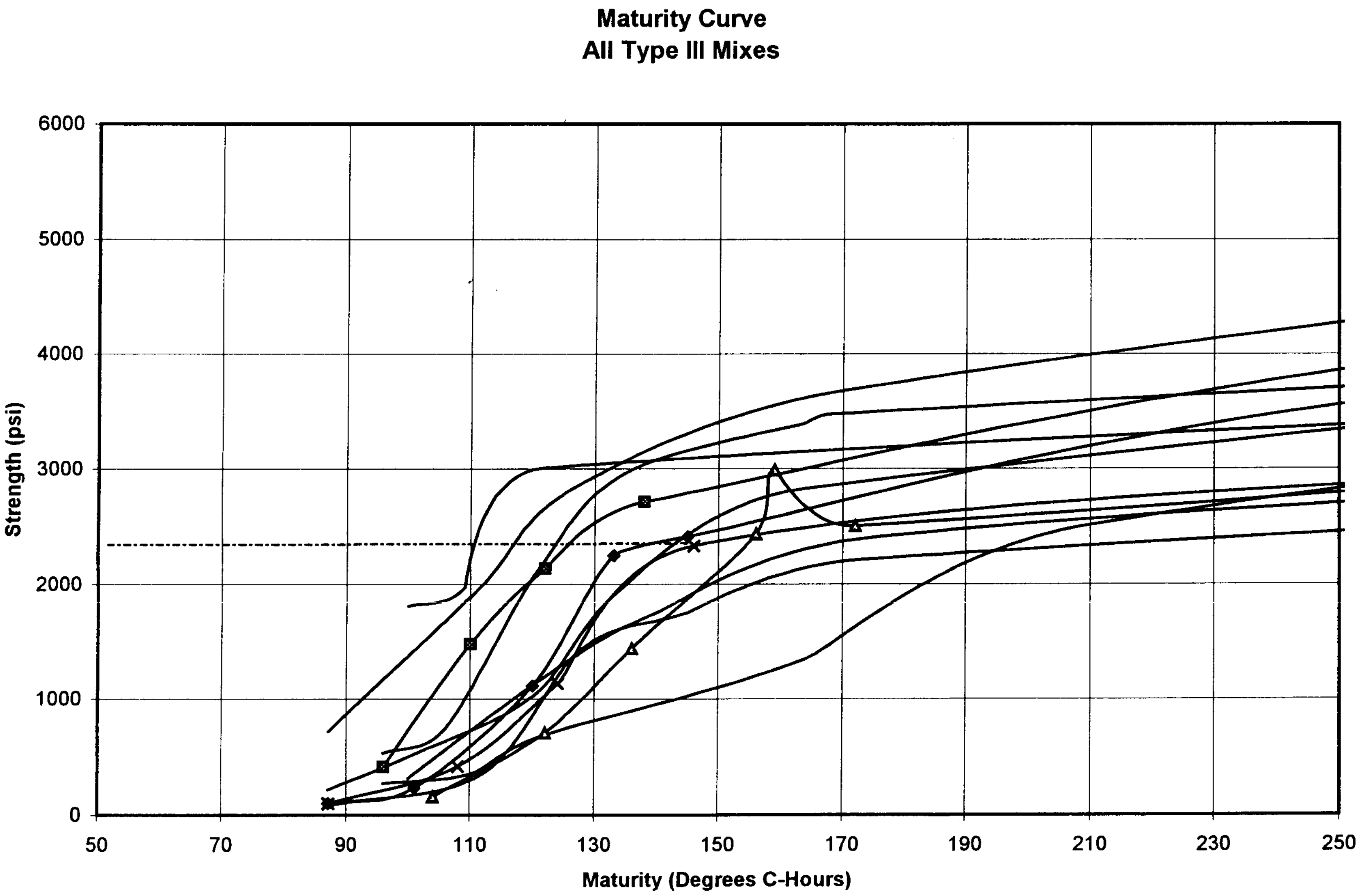

Fig.20 Strength maturity curve for all type-III cements.

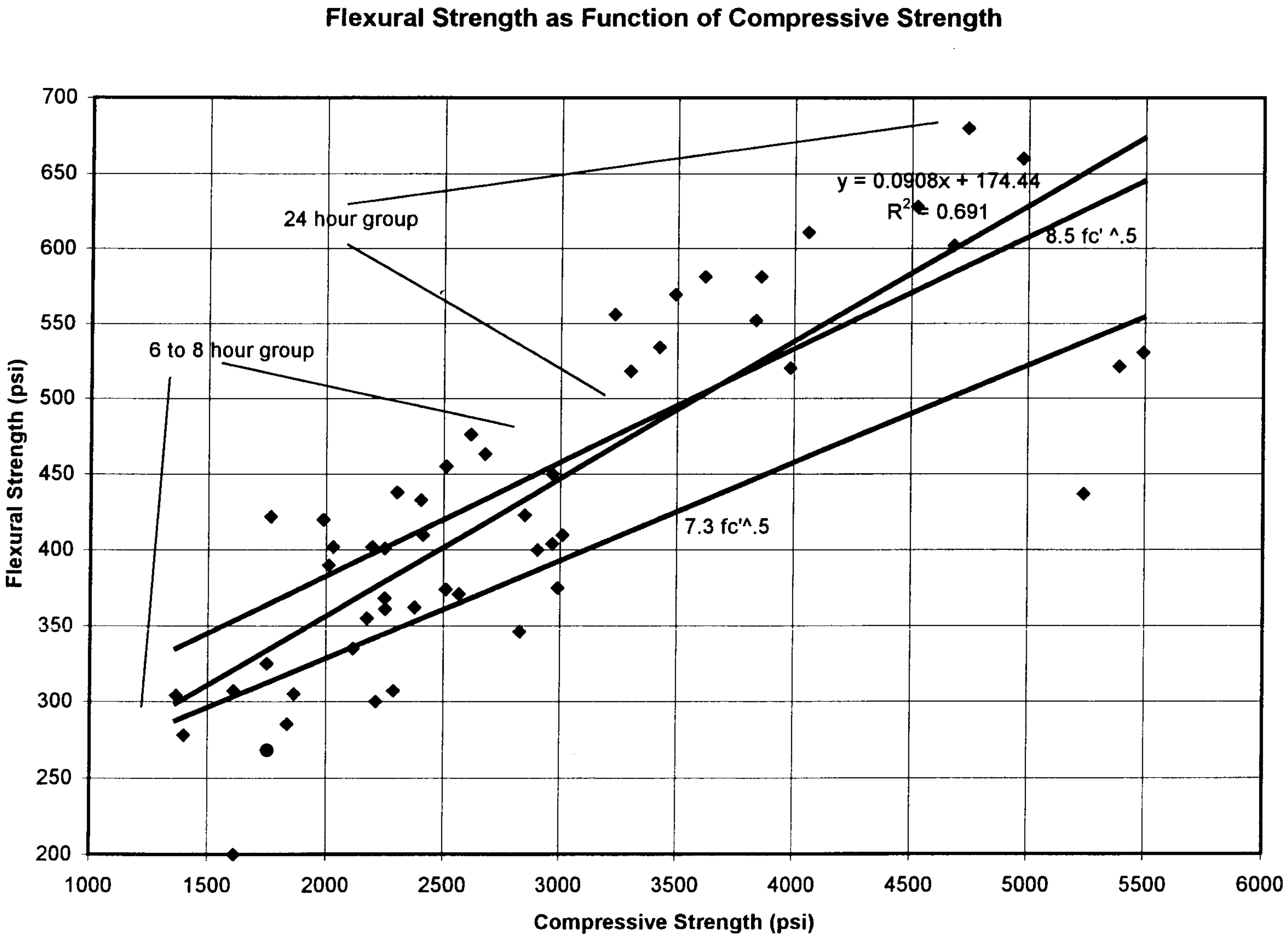

Fig. 21 Flexural strength versus compressive strength for fast-track mixes.