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PRODUCTION OF MASONARY BLOCKS FOR DEVELOPING COUNTRIES

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Introduction

The need for nurturing of low cost building materials industry in developing countries has long been recognized throughout the world (1) • The inflation trend of the world economy have escalated the costs of building materials. Therefore, construction of low cost housing has become more difficult.

The objective of this research was to utilize minimal cost materials, such as coal combustion by-products (fly ash, bottom ash, etc.), for production of masonry blocks for low cost housing construction. The research was done in two phases. The first phase (3) was designed to identify mixtures of fly ash and binder which would yield blocks of sufficient strength to withstand handling, transfer and long term exposure. The final phase (4) was designed to

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determine the response of acceptable fly ash block mixtures, from Phase I study, to continued soaking in fresh water. *The* water in the tank was continuously charged with a very low rate of flow (about one gallon per minute).

The experimental design required that the fly ash blocks be tested periodically over a two-year period for compressive strength, pulse velocity, density and surface hardness. The results of this phase of study, as well as complete data for trial mix proportions from the Phase I study, are presented in the following sections.

Mix Proportions

The Phase I study resulted in selection of five basic mixtures of fly ash and various binders that could be used in the mass production of fly ash masonry blocks (3). The fly ash used was produced by Wisconsin Electric's coal-fired power plants. The criteria for selecting these mixtures was to meet or exceed the following:

(1) to be compatible with current block making techniques;

(2) to use coal combustion waste material (fly ash) to the maximum extent possible while minimizing costs (e.g., amounts of additives); and,

(3) the fly ash blocks must reach a strength of 300 + 50 psi (2100 + 350 KN/m^2) within two days to permit handling, stacking, and transportation.

All of the five fly ash block mix designs evaluated in the next phase of this Research exceeded this criteria.

Mix proportions for the five types of fly ash blocks are presented in Table 1.

Experimental Setup

All blocks were produced by Bend Industries, West Bend, Wisconsin, using a 75 percent solid mold design and standard block fabricating procedures (4). Forty 8x8x16 in. (203x203x406 mm) blocks representing each mix design were randomly selected from a single batch run. Using blocks from a single batch run had the potential to reduce test variability among blocks. In addition, blocks with obvious surface imperfections were rejected to avoid invalid compressive strength test results.

The blocks were placed in five 300 gallon (1.14 m^3) galvanized steel tanks. Milwaukee tap water, which is treated Lake Michigan water, was supplied continuously to each tank. Water temperature was monitored by a continuous recorder. Over the course of this study, two years, water temperature ranged between 40° and 63°F (4 and 17 °C).

Experimentation

Two experiments with separate groups of fly ash blocks representing each of the five mix proportions were conducted. In the first experiment, three blocks representing each mix were randomly selected and removed from the tanks for testing on each designated test day (day 1, weeks 2, 4, 8, 14, 26, 41, 52, 64, 72, 91 and 104). Each block was first weighed in water and then in air. Block dimensions were then measured. This data was used to compute block density.

After each block was weighed, measured and identified, pulse velocity measurements through the height of the block and along the block surface were recorded, Figure 1. Each block was also tested for surface hardness using an impact hammer. The blocks were then capped and tested for compressive strength according to ASTM Test Designation C-140 (2).

In the second experiment, pulse velocity and surface hardness measurements were repeated on the same blocks over the two-year testing period. These blocks were not destructively tested for compressive strength.

The purpose of the second experiment was to evaluate the pulse velocity measurements as a substitute of the surface hardness and the destructive compressive strength measurements, respectively. Only results of the first experiment are reported in this paper.

Discussion of Results

Compressive Strength and Density Tests

Figures 2 through 6 show trends in fly ash block mean compressive strength and density values for the five mix designs through two years of continuous soaking in freshwater.

Ail blocks from the five mixes gained appreciable strength over the two years, Table 2. However, the blocks from Mixes 1, 2 and 3 attained maximum strength at one year age. Figures 2, 3 and 4, then they exhibited a slight decrease in strengths through the remaining one year of the experiment. The blocks from the Mix 4 attained greatest strength at the 21 month age. Figure 5, while blocks from the Mix 5 continued to gain strength through the entire period reaching its maximum value at the 2 years age, Figure 6.

Density values for all fly ash block mixes also increased over the two-year period, Figures 2-6 and Table 3. Blocks from the Mix 1 exhibited the most consistent increase. Figure 2. Conversely, blocks from Mixes 2, 3 and 4, Figures 3, 4, and 5, exhibited rather erratic trends in density. Finally, blocks from the Mix 5 exhibited a very consistent increasing trend through the first year followed by a rather erratic pattern through the remainder of the experiment, up to the end of the second year. Figure 6. Trends in block density values did not appear to closely mirror trends in block compressive strength values for the same mixes except for Mixes 1 and 4.

Using compressive strength as an indicator of fly ash block integrity, only fly ash blocks from Mixes 4 and 5 appeared to be unaffected by the two-year period of continued soaking. On the other-hand, the trends in density values for these two mixes suggest the opposite. As will be discussed later, there are additional criteria to consider when judging fly ash block integrity in response to long term immersion.

Surface Hardness Measurements

Impact hammer measurements (average of 12 readings per block, a minimum of 36 readings per mix) for each test age are plotted in Figures 7 and 8. Other similar types of figures for other mixes are not shown herein-due **to** space limitations.

Two of the five mixes (Mixes 1 and 2) exhibited clear indications of decreasing surface hardness over time as measured by this technique, Figures 7 and 8. However, the Mix 3 while not exhibiting any definitive trend, had the softest surface of the five mixes while the Mix 4 had the hardest surface. Blocks from the Mix 5 exhibited little variation as a function of immersion time while blocks from Mixes 1, 2 and 4 exhibited substantial variability between sampling dates.

In part, the observed variability is believed to reflect the limits of the sensitivity of this test procedure. The impact hammer test is usually applied to substances that are considerably harder than fly ash block materials (e.g., structural strength concrete). The fly ash blocks being tested have an apparent hardness of only a few units above the test threshold reading of ten. With this limitation, the impact hammer test may not have the sensitivity to detect subtle changes in fly ash block surface hardness. However, the test does appear to have the ability to detect gross changes in surface hardness. As evidenced by the data, blocks from Mixes 1 and 2 exhibited gross changes in surface hardness.

Finally, using surface hardness as a indicator of fly ash block integrity, only fly ash blocks from Mixes 4 and 5 appeared to be unaffected by the two year period of continued immersion.

Pulse Velocity Measurements

Two sets of ultrasonic pulse velocity measurements were taken across the height of the block. The set of measurements denoted "across" on Figures 9 and 10 were at points A-F, Figure 1, while those denoted "along" on Figures 9 and 10 were taken at points A'-F', Figure 1, for Mix 1 and 2. Other similar types of figures for other mixes are not shown herein due to space limitations. The measurement locations A-F were chosen to represent the load bearing points of the block. The pulse velocity readings collected along these profiles were thought to best correlate with compressive test results which in turn represent the maximum load that leads to structural failure during testing (5).

On the other hand, the measurement locations A'-F' were selected to correspond with the block surface plane. Imperfections in or softening of the surface of the block would tend to refract the sound waves causing diminished velocity measurements (6). The "along" surface velocity measurements were correlated with

surface hardness measurements taken during the same sampling period to test the hypothesis that "along" surface sound velocity could be used to detect surface softening (6).

The results for the "across" velocity measurements, Figures 9 and 10, very closely resemble the compressive strength curves for the respective mix designs, Figures 2 and 3. Other similar pulse velocity measurements for mixes 3, 4, and 5 also resembled compressive strength plots for these mixes, Figures 4, 5 *and* 6. The "across" velocity and corresponding compressive strength values were examined for statistical correlation, the results of which are summarized in Table 4.

These analyses indicate that the "across" velocity measurement is highly correlated with strength and density for all mixes. With respect to surface hardness the correlation was very poor except for mixes 1 and 5. The results for the "along" velocity measurements, Figures 9 and 10, mirror the surface hardness data for mixes 2 and 5. The correlation statistics for the "along" pulse velocity, compressive strength, density and surface hardness values are also summarized in Table 4. While "along" pulse velocity correlates reasonably well with compressive strength, except for Mix 1, the correlation with density is generally poor. However, pulse velocity "along" measurements correlate very well with surface hardness measurements for Mixes 2 and 5.

Summarizing the above discussion, the conclusion is that pulse velocity "across" measurements gave the same trend as the compressive strength measurements for the different mixes. Also, pulse velocity "along" measurements gave approximately the same trend as the surface hardness measurements. Therefore, using pulse velocity measurements as an indicator of fly ash block integrity, once again only fly ash blocks from mixes 4 and 5 were unaffected by the two-year period of continuous soaking.

Conclusions

The following conclusions can be drawn from this research:

(1) Fly ash masonry blocks can be produced and designed to meet very low cost housing material specifications.

(2) All five fly ash block mix designs exhibited 100% increases in compressive strength. Mixes 4 and 5 exhibited increases exceeding 150%.

(3) Three of the five mix design (Mixes 1, 2 and 3) blocks exhibited surface softening. Due to unstable surfaces, these block types would be unacceptable for low cost construction materials.

(4) The pulse velocity method can be used to monitor evolving block strength and surface stability.

Appendix I - References

(1) "Appropriate Building Materials for Low Cost Housing", CIB and RILEM, Symposium proceedings, published by E. and F.S. Spon, New York, 1983, 524 **pages**.

(2) "Annual Book **of** ASTM Standards", Part 14, American Society **for** Testing and Materials, Philadelphia, PA, 1985.

(3) *"Ply* Ash Block Artificial Reef Project, Phase One Final Report", Wisconsin Electric Power Company, Milwaukee, WI, March 1985, 60 pages.

(4) "Fly Ash Block Artificial Reef Project, Phase Three Final Report", Wisconsin Electric Power Company, Milwaukee, WI, October 1987, 30 pages.

(5) Naik, T.R., "Ultrasonic Testing of Concrete", Experimental Methods in Concrete Structures for Practitioner, Washington, D.C., October 1979, 33 pages.

(6) Naik, T.R., "NDT Methods for Testing Fly Ash Blocks", Report prepared for Wisconsin Electric Power Company, Milwaukee, WI, October 1983, 17 pages.

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Table 1: FLY ASH BLOCK MIX PROPORTIONS

Mix No.	Test Series Number	Fly Ash Source	Composition[a], % Dryweight: Fly Ash	Cement	Lime	Class C[b] Fly Ash	Compressive Strength at 2-day, psi	Compressive Strength at 7-day, psi
1	21	Valley Power Plant	72	8	0	0	557[c]	729
2	45	Oak Creek Power Plant	76	4	0	0	612[c]	717
3	52	Oak Creek Power Plant	76	0	4	0	405[c]	549
4	60	Oak Creek Power Plant	55	0	0	25	429	541
5	73	Valley Power Plant	50	0	0	30	388	532

Note: 1 psi = 6.9 KN/m^2

[a] All mixes contained 20% 3/8 inch (10 mm) maximum size rounde aggregates (gravel).
[b] Class C fly ash used as a cementitious binder.
[c] Cured in air after initial steam curing.

Table 2: INCREASES IN FLY ASH BLOCK STRENGTH AFTER TWO YEARS OF CONTINUOUS SOAKING IN FRESH WATER

Mix No.	Compressive Strength, psi 7 days age	2 Years age	Increase	% increase
1	729	904	175	124
2	717	949	232	132
3	549	751	202	137
4	541	1000	459	185
5	532	1165	633	219

Note: 1 psi = 6.9 KN/m^2

Table 3: <u>CHANGES IN FLY ASH BLOCK DENSITY AFTER TWO YEARS OF CONTINUOUS SOAKING IN FRESH WATER</u>

Mix No.	Density (g/cm^3) 7 days age	2 Years age	Increase	% increase
1	1.71	1.78	0.07	+4.1
2	1.88	1.91	0.03	+1.6
3	1.88	1.94	0.06	+3.2
4	1.86	1.89	0.03	+1.6
5	1.80	1.85	0.05	+2.8

Note: 1 lb./cu.ft. = 0.016 g/cm^3

Table 4: CORRELATION STATISTICS FOR PULSE VELOCITY MEASUREMENTS

Mix No.	Parameter	Pulse Velocity "across"		Pulse Velocity "along"	
		Coefficient	Probability	Coefficient	Probability
1	Compressive Strength	0.664	0.0001	-0.151	0.452
	Density	0.851	0.0001	-0.522	0.005
	Surface Hardness	-0.661	0.0002	0.318	0.106
2	Compressive Strength	0.706	0.0001	0.771	0.0001
	Density	0.797	0.0001	0.389	0.045
	Surface Hardness	-0.068	0.736	0.441	0.021
3	Compressive Strength	0.847	0.0001	0.588	0.002
	Density	0.471	0.005	0.235	0.258
	Surface Hardness	-0.281	0.165	0.001	0.997
4	Compressive Strength	0.877	0.0001	0.812	0.0001
	Density	0.477	0.003	0.351	0.073
	Surface Hardness	-0.219	0.273	-0.123	0.539
5	Compressive Strength	0.859	0.0001	0.657	0.003
	Density	0.725	0.0001	0.333	0.089
	Surface Hardness	0.411	0.036	0.579	0.002

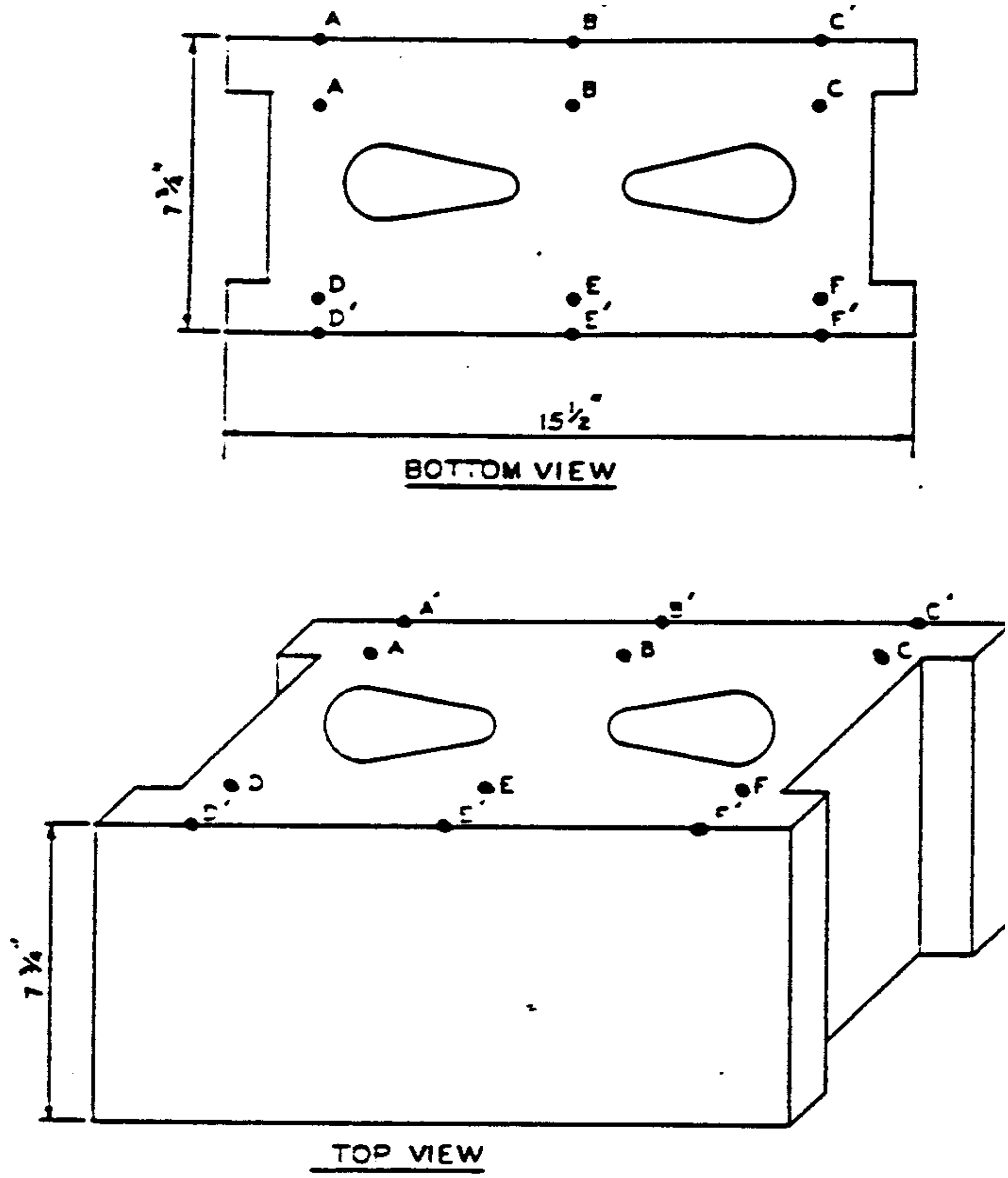

Figure 1 Diagram depicting transducer placement locatior
for pulse velocity measurements.

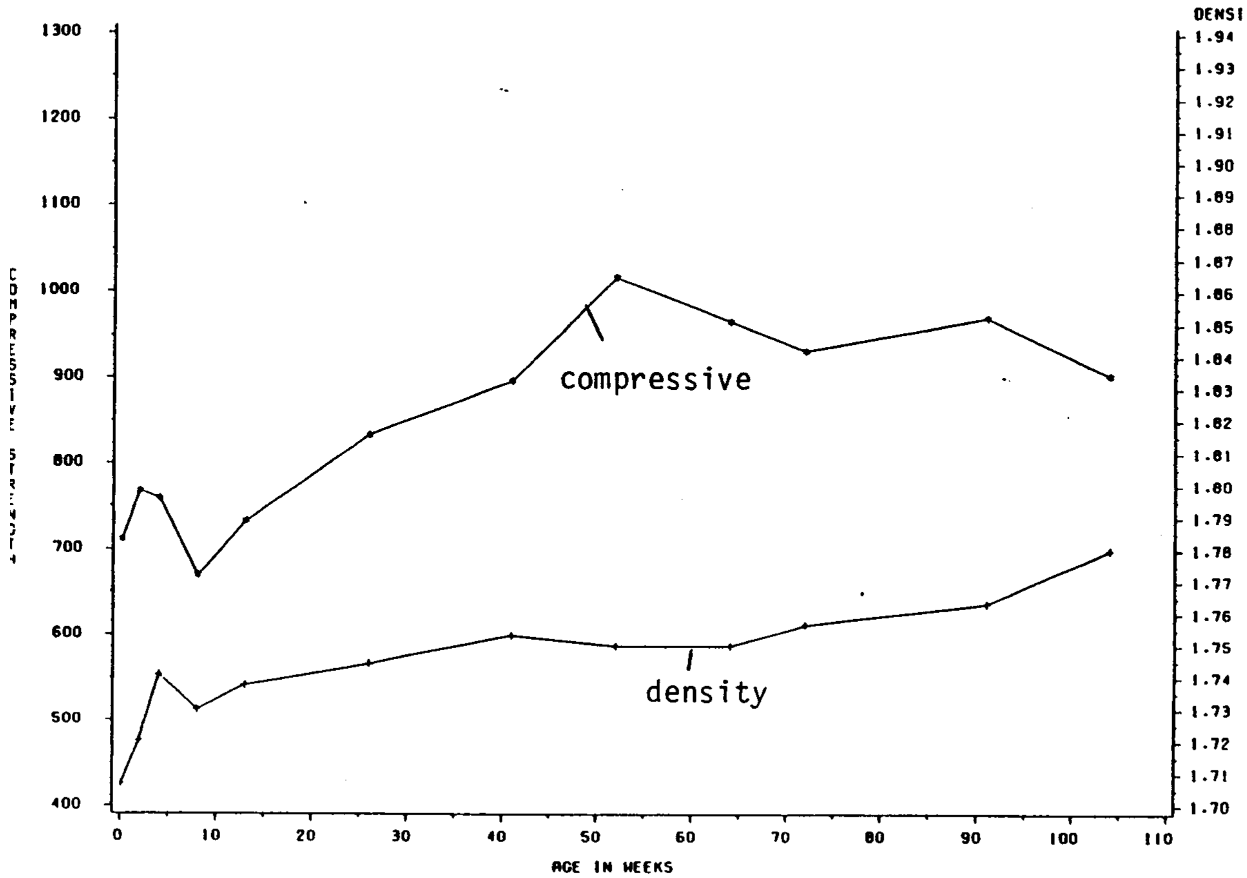

Figure 2 Compressive strength and density versus age,

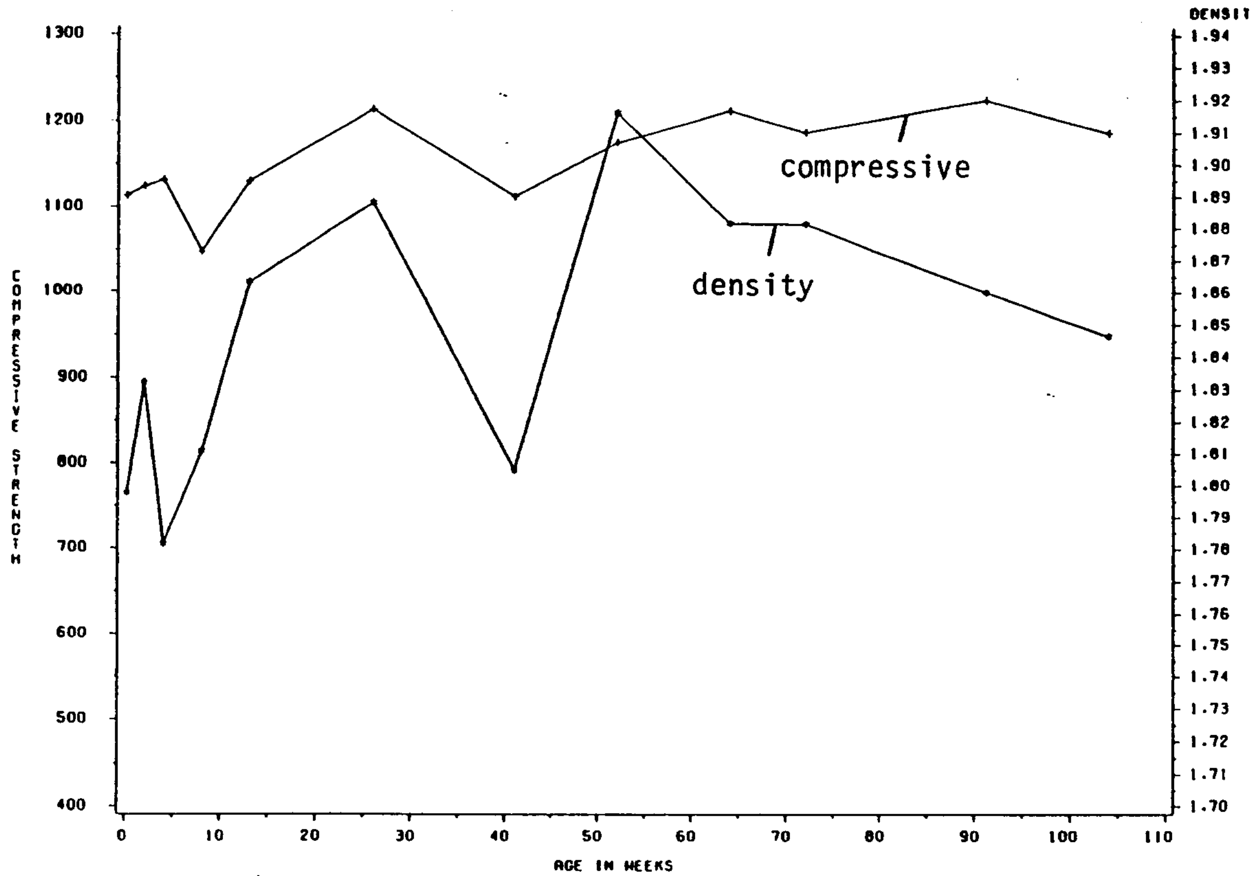

Figure 3 Compressive strength and density versus age, Mix No. 2

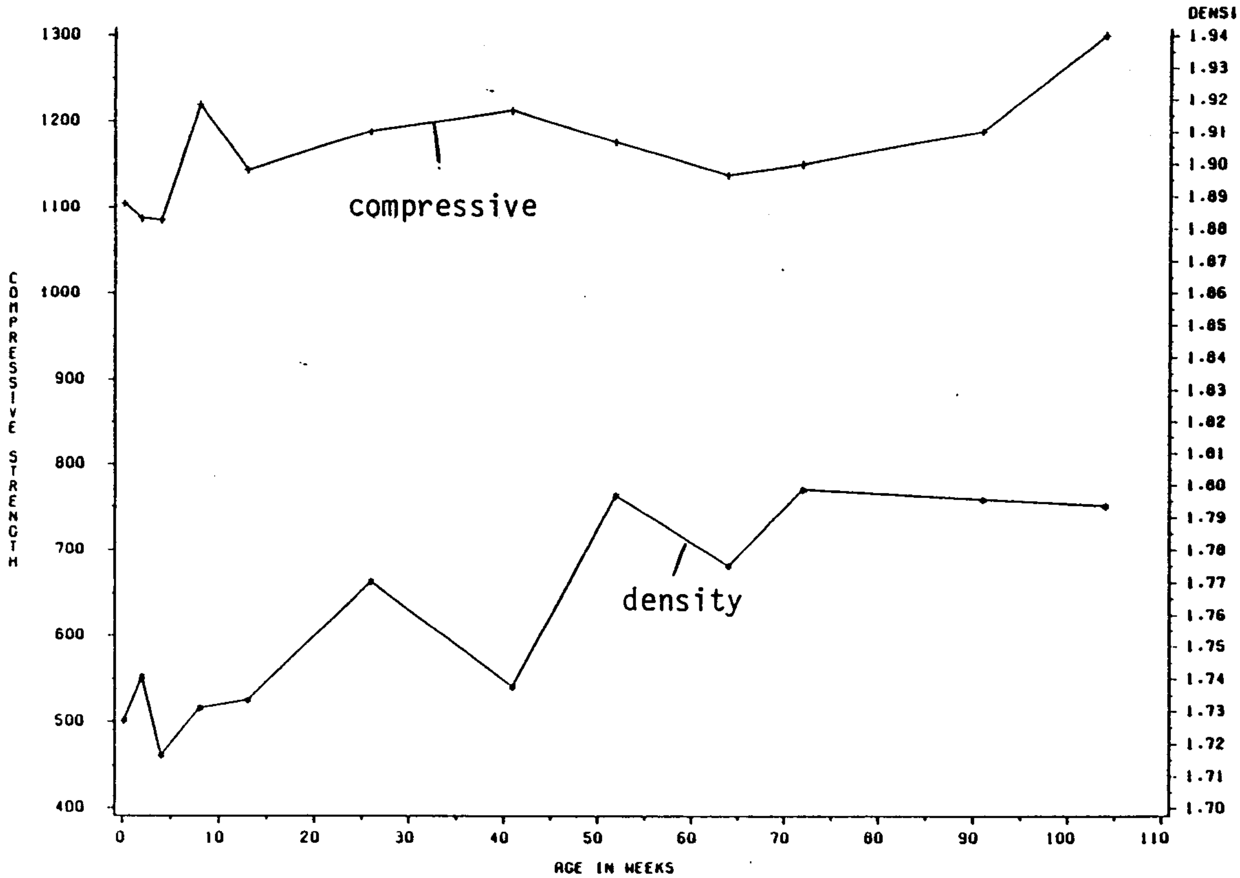

Figure 4 Compressive strength and density versus age

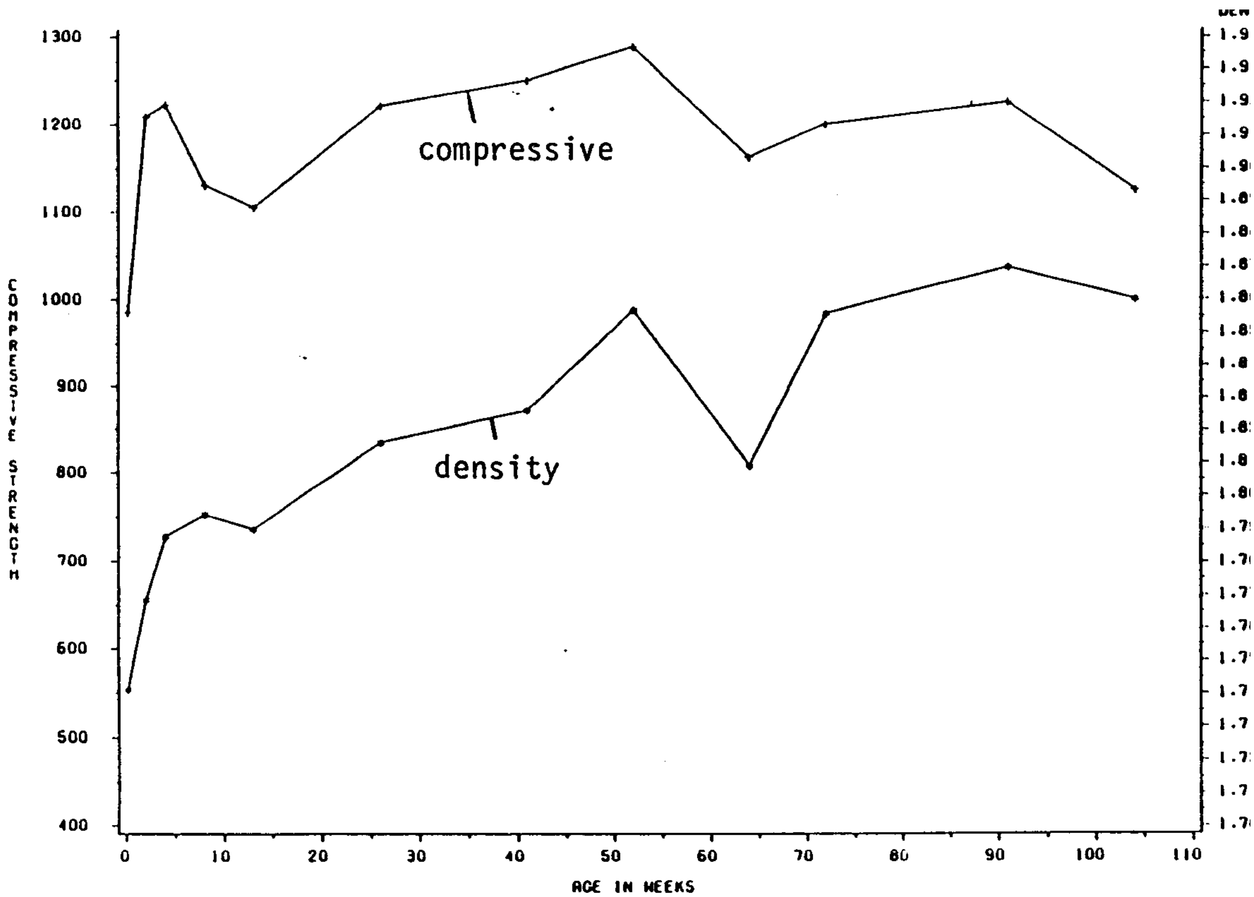

Figure 5 Compressive strength and density versus age,
Mix No. 4

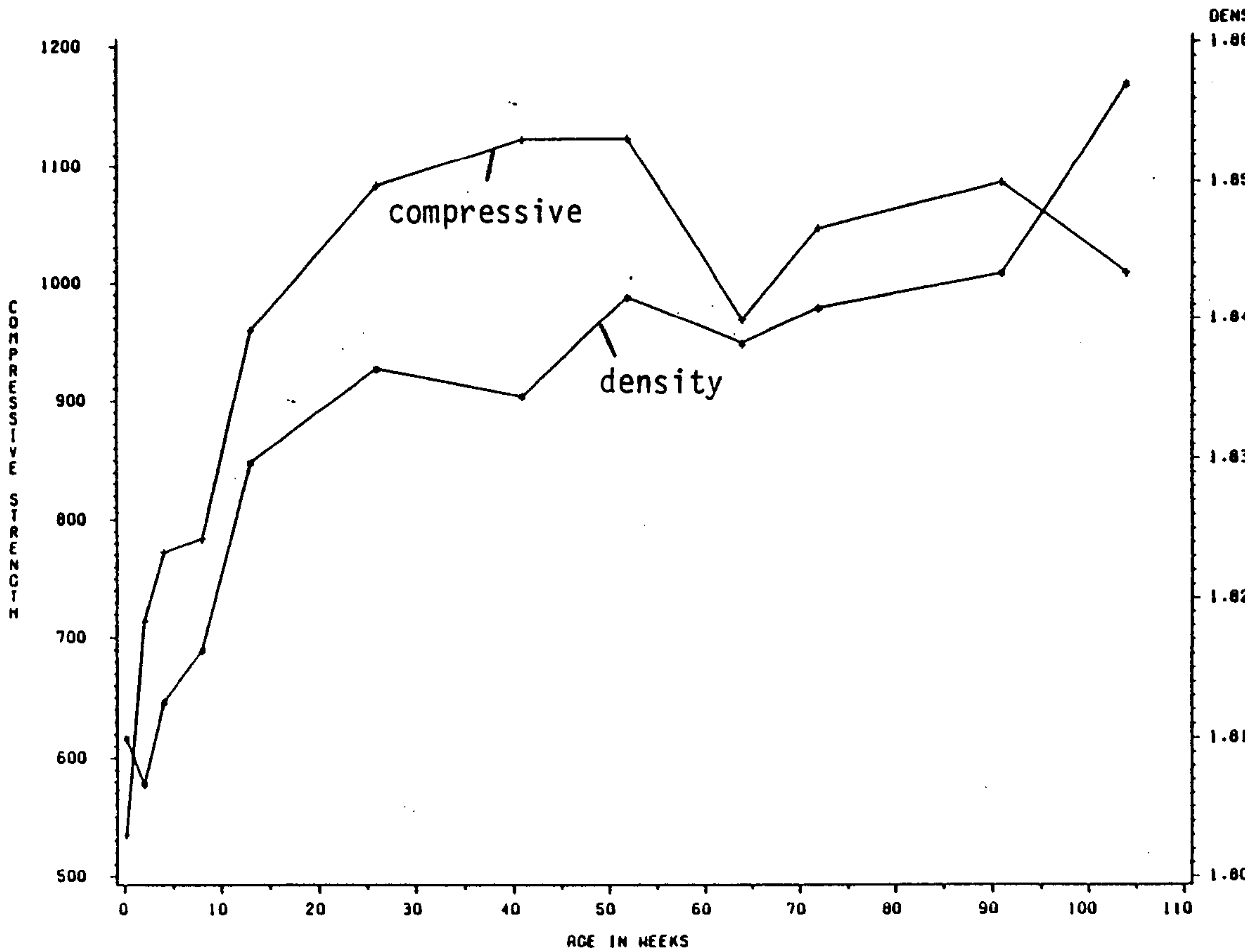

Figure 6 Compressive strength and density versus age,

Mix No. 5

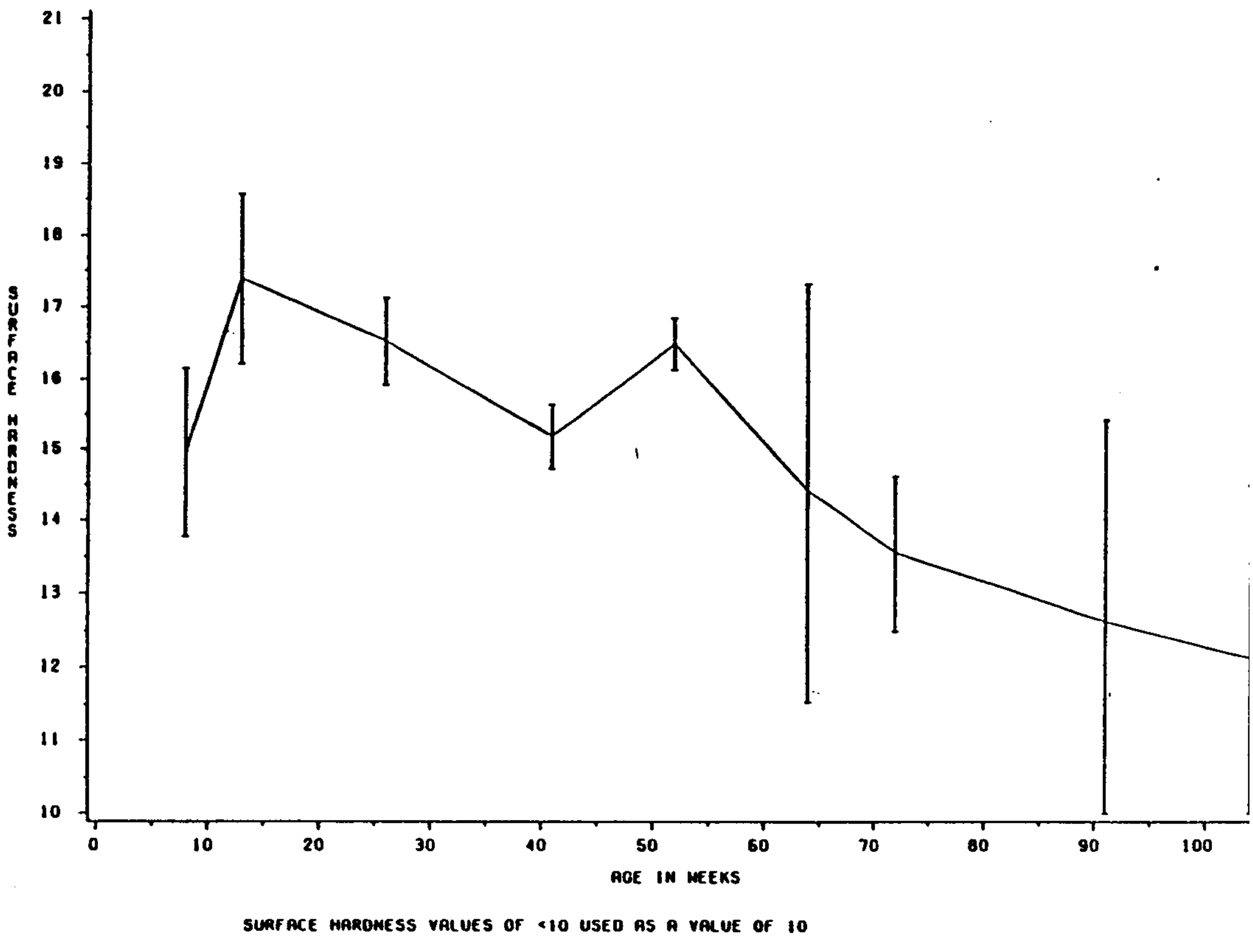

Figure 7 Surface hardness versus age. Mix No. 1.

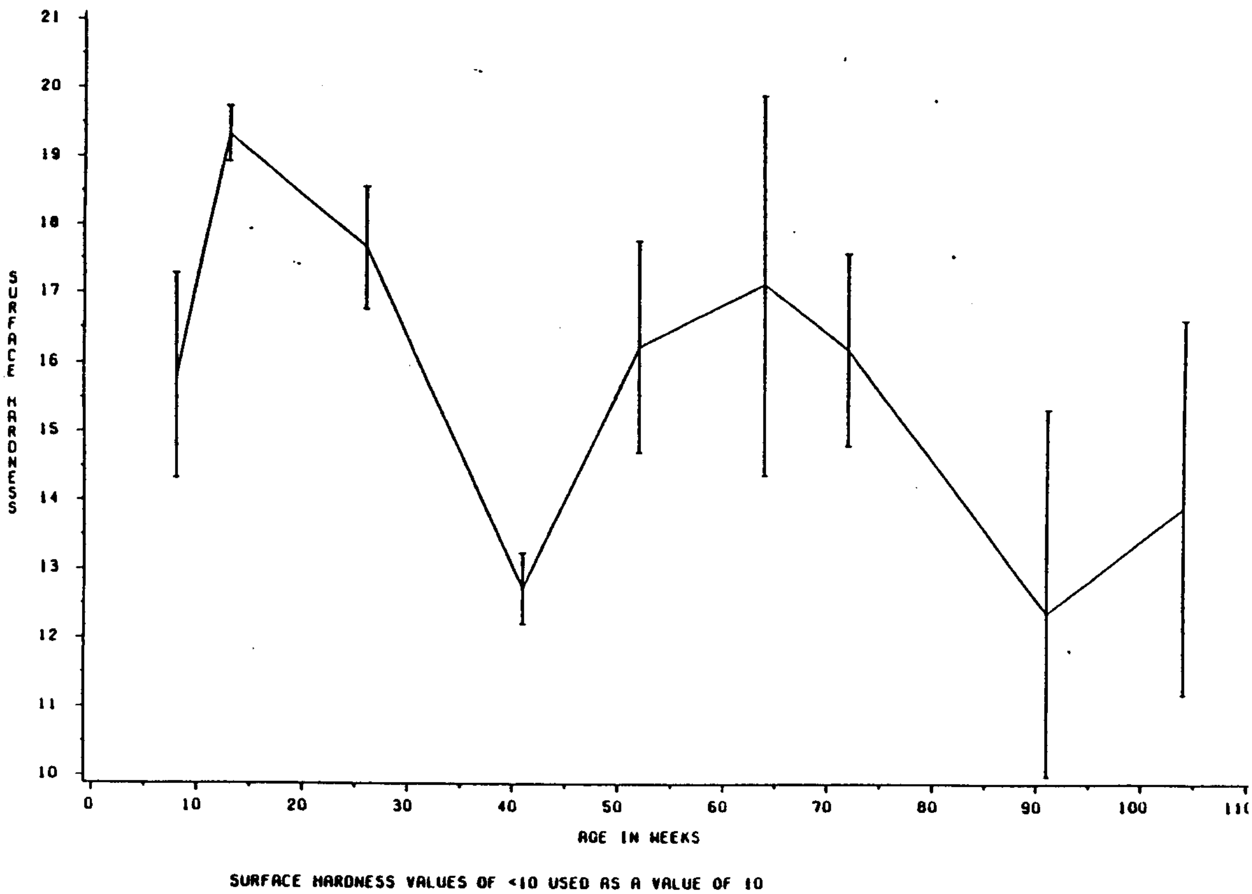

Figure 8 Surface hardness versus age, Mix No.2

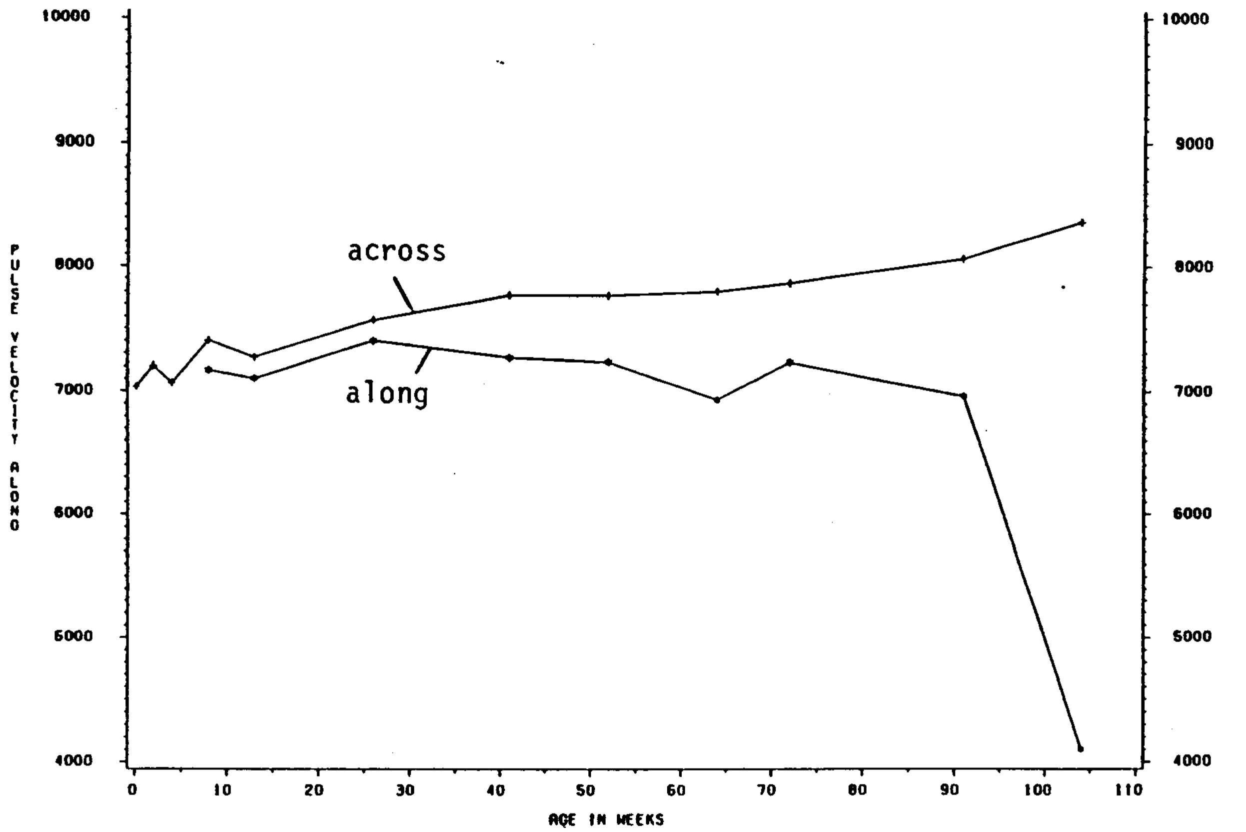

Figure 9 Pulse velocity versus age Mix No 1

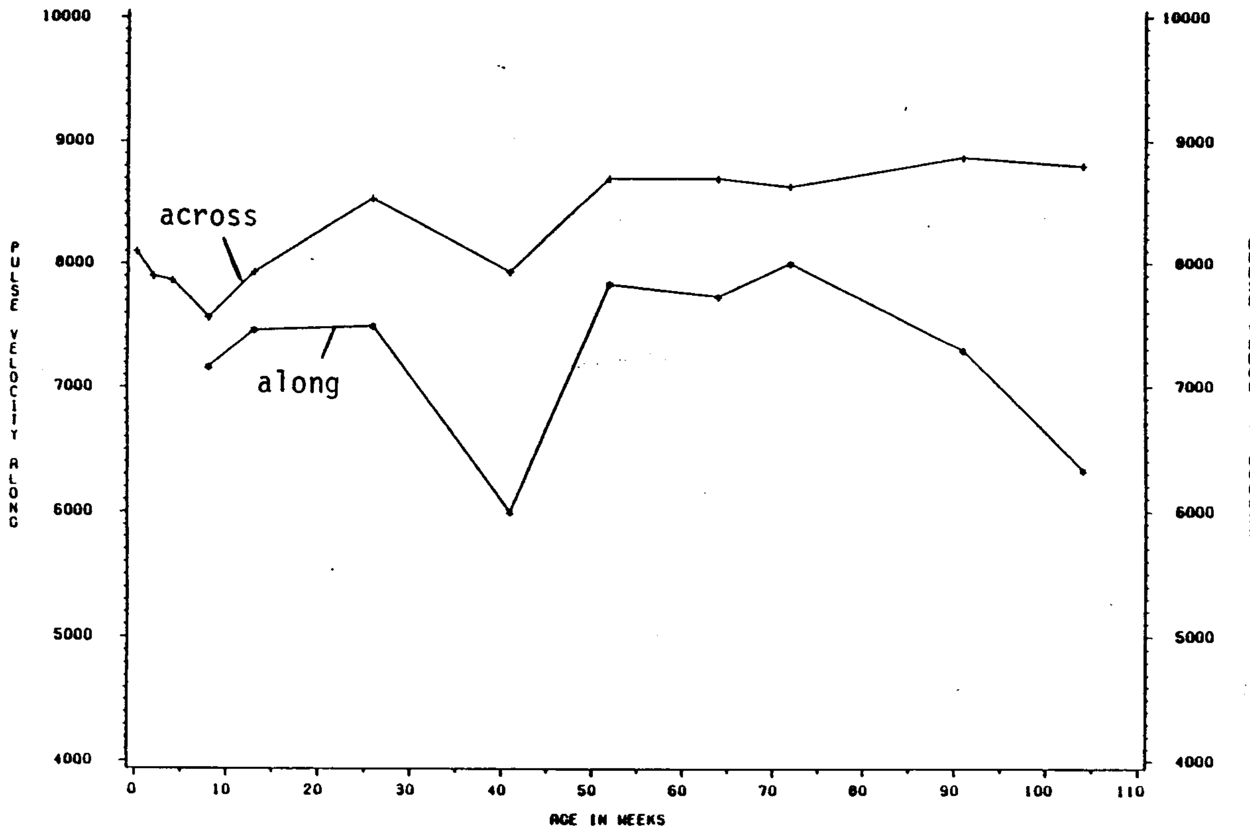

Figure 10 Pulse velocity versus age Mix No 2