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Durability of Epoxy Bond

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PROJECT SUMMARY

This report presents interim results from a study to evaluate the durability of epoxy used for bonding carbon fiber fabric and uni-directional carbon material to concrete. A total of 24 specimens using three different carbon fiber materials and five different epoxy systems were tested. Several of these specimens were deliberately provided with blemishes to reflect likely field situations.

Nineteen unstressed specimens including some that were blemished, were subjected to three environments a) wet/dry cycles in salt water, b) thermal cycling in salt water and c) outdoors. The performance of these specimens was qualitatively evaluated by comparison with its original state and also with that of control specimens kept in an air-conditioned laboratory. After over five months exposure over the period June-December 1995, very little deterioration was observed in the blemish-free exposed specimens and none in the control specimens. Only one blemish-free specimen exposed to thermal cycling showed localized evidence of debonding. Two others that were exposed outdoors, discolored without debonding. Some of the specimens that were defective to begin with, showed some increase in the extent of the original debonded area. Overall, the preliminary results are very promising and suggest that several different epoxy systems are likely to be durable in Florida's harsh environment.

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1. INTRODUCTION

The University of South Florida is conducting a study to assess the long term durability of the epoxy bond between carbon fiber reinforced plastic (CFRP) material and concrete. 24 specimens prepared by FDOT are being used in the study.

Three different types of carbon fiber materials and five different epoxies are being investigated. The specimens, each 18 in. x 18 in. in plan, have been placed in four different environments - a) air-conditioned laboratory *termed control,* b) thermal wet/dry cycles in 5% salt water *termed bond c)* wet/dry cycles in 15% salt water *termed durability* and d) outdoor conditions, *termed outdoor.*

Of the 24 specimens in the study, one each of the five different CFRP/epoxy combinations, is used as a control. The remaining 19 are being used in the exposure study. Details of the breakdown of the number of specimens in each of the four environments are summarized in

Table 1. Exposure Matrix for Test Specimens.

Specimen Name	Epoxy Details (As identified by FDOT)	#	Exposure type and #			
			Controls	Bond	Dura-bility	Outdoor
FA2	Aeroepoxy two layers	6	1	2	2	1
FAH2	Aeroepoxy/Henkle two layers	6	1	2	2	1
T2	Tonen epoxy primer-Mitsubishi fabric	4	1	1	1	1
MP2	Mitsubishi Epoxy/Primer/Putty/Fabric	4	1	1	1	1
FAHP2	Aeroepoxy/ Henkle/Mitsubishi Putty	4	1	1	1	1

The exposure testing commenced on June 20, 1995. This report presents interim results until December 20, 1995.

24 specimens were shipped to USF on June 19, 1995. Prior to exposure of the specimens to the different environments, inspections were carried out to detect if there were any defects. This indicated the presence of minor defects in several of the specimens particularly in the FAH2: and FAHP2 series. Summaries of the initial inspection are contained in Tables *2-6. (Photographs showing*

Table 2. Aerospace Two layers Specimens.

Specimen	Slab Dimension	Epoxy Dimension	Comments
FA2-1	18 x 18 x 3.5	16 x 16	2 in x 2.5 in bump near corner
FA2-2	18 x 18 x 3.75	16.5 x 17	PERFECT
FA2-3	18 x 18 x 3-3.75	16.5 x 16.5	PERFECT
FA2-4	18 x 18 x 3.25	16.75 x 16	PERFECT
FA2-5	18 x 18 x 4	16.5 x 16.5	PERFECT
FA2-6	18 x 18 x 3.5	16 x 16	*Control*

Table 3. Inspection Summary for Aerospace/Henkle Specimens.

Specimen	Slab Dimension	Epoxy Dimension	Comments
FAH2-1	18 x 18 x 3.75	16.5 x 16.5	corner NG; bump at edge 0.5 x 1 in.
FAH2-2	18 x 18 x 3	16 x 16	*Control*
FAH2-3	18 x 18 x 3.25	16.5 x 16.5	bubble on side - debonding that side
FAH2-4	18 x 18 x 3.75	16.25 x 16	blemish in material at one location
FAH2-5	18 x 18 x 3.25-3.5	16 x 16.5	no bumps but edge near marking poor
FAH2-6	18 x 18 x 3.5	16 x 16.5	PERFECT

Table 4. Tonen Epoxy Primer-Mitsubishi Fabric Specimens.

Specimen	Slab Dimension	Epoxy Dimension	Comments
T2-1	18 x 18 x 3	16.25 x 16.25	PERFECT
T2-2	18 x 18 x 3	17 x 17	*Control*
T2-3	18 x 18 x 3	16 x 16	PERFECT
T2-4	18 x 18 x 3	16.5 x 16	PERFECT bond but rough surface texture

Table 5. Mitsubishi/Epoxy/Primer/Putty Fabric Specimens.

Specimen	Slab Dimension	Epoxy Dimension	Comments
MP2-1	18 x 18 x 3	17 x 14.5	*Control*
MP2-2	18 x 18.5 x 3.75	16 x 17	PERFECT
MP2-3	18 x 18 x 3.5	14 x 16.5	PERFECT
MP2-4	18 x 18.25 x3.75	16.25 x 16.25	PERFECT

Table 6. Aerospace/Henkle/Mitsubishi Putty Specimens.

Specimen	Slab Dimension	Epoxy Dimension	Comments
FAHP2-1	18 x 18 x 4	17 x 16.25	Bubble at corner-epoxy missing at corner
FAHP2-2	18 x 18 x 3.5	16 x 16.5	*Control*
FAHP2-3	18 x 18 x 3.5	16.5 x 17	Bubbles at corners and along edge. Defect between layers
FAHP2-4	18 x 18 x 3	16 x 17	Corner loose (number); bump opposite side

3. **EXPOSURE DETAILS**

As stated already, nineteen specimens were exposed to the three different exposure environments listed in Table 1. Additional information on the environments is provided in this section.

A. **BOND:** *Specimens FA2-1, FA2-3, FAH2-3, FAH2-5, T2-4, MP2-2, FAHP2-1*

A total of seven specimens were placed in two insulated tanks (Tanks 1 and 2) containing 5% salt water. At "high" tide, the temperature of the water was increased to 60°C; at "low tide" the tank was left uncovered so that the temperature dropped to the ambient level. The tide was changed bi-weekly. A photograph of the two tanks is shown in Plate 1. At "low aide" the epoxied surface was completely dry (see Plate 3); at high tide it was completely submerged (Plate 4). Information on the water temperature for the tanks is included in Appendix A.

Of the seven specimens, the epoxy was not perfectly bonded to the concrete surface in two specimens. These were FAH2-3 (Table 3) and FAHP2-1 (Table 6). The remaining specimens were free of major blemish though the concrete surface on occasion was not perfectly smooth, e.g. FA2-1 (see Table 2).

B. **DURABILITY:** *Specimens FA2-2,FA2-5, FAH2-1, FAH2-4, T2-3, MP2-3 & FAHP2-3*

A total of seven specimens were placed in two tanks (Tanks 3 and 4) containing 15% salt water at the ambient temperature. The tanks were covered by a plastic sheet as shown in Plate 2 to provide increased humidity. The water level in the tanks was changed weekly to simulate tidal effects. As for the bond study, at "low" tide, the epoxied surface was completely dry; at "high" tide it was completely submerged as shown in Plates 3 and 4. Information on the water temperature variation in the tanks is included in Appendix B.

Of the seven specimens, six were free of major blemishes. Only one specimen, FAHP23 (Table 6) had defects.

C. **OUTDOORS:** *Specimens FA2-4, FAH2-6, T2-1, MP2-4 and FAHP2-4*

Five specimens, one from each representative group being tested, were placed outdoors on wooden pallets at the ground level and, subjected -to changing weather conditions for the duration of the study (see Plate 11). The variation in ambient conditions as reported by the *Tampa Tribune is* provided in Appendix C.

Of the five specimens exposed, one, FAHP2-4 (Table 6) had minor blemish

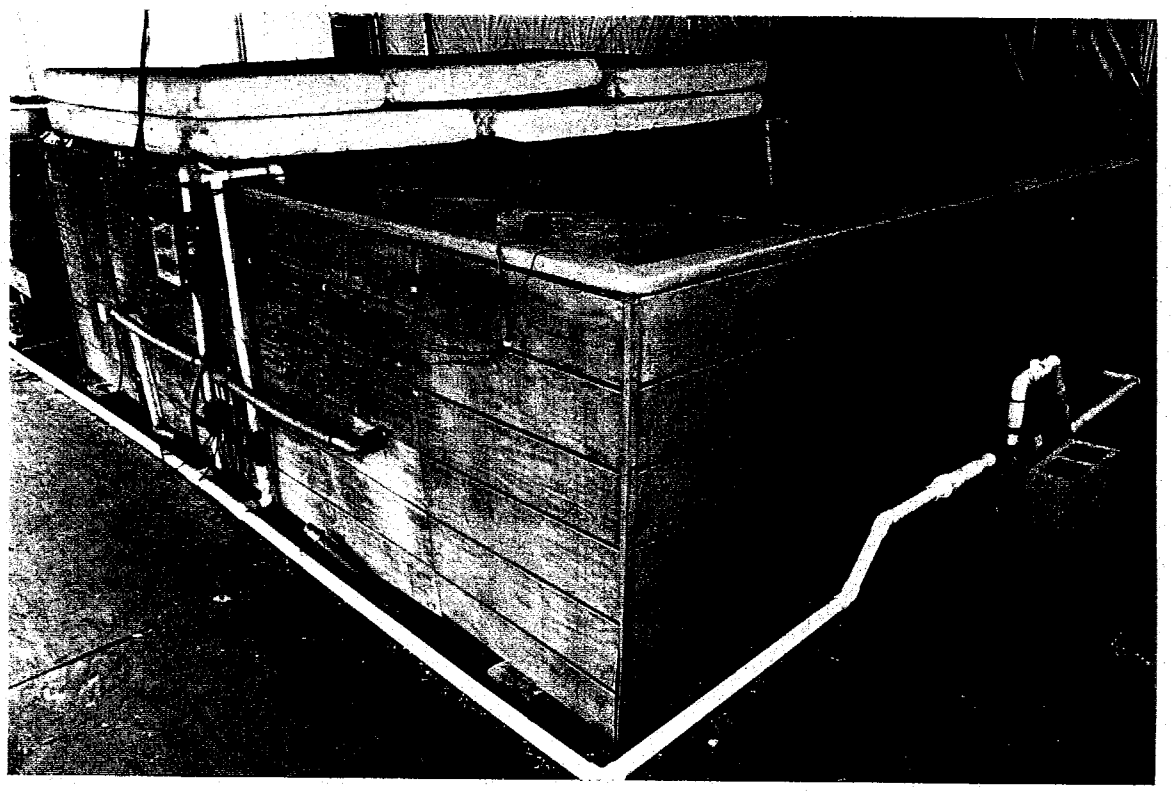

Plate 1. Bond Study Tanks.

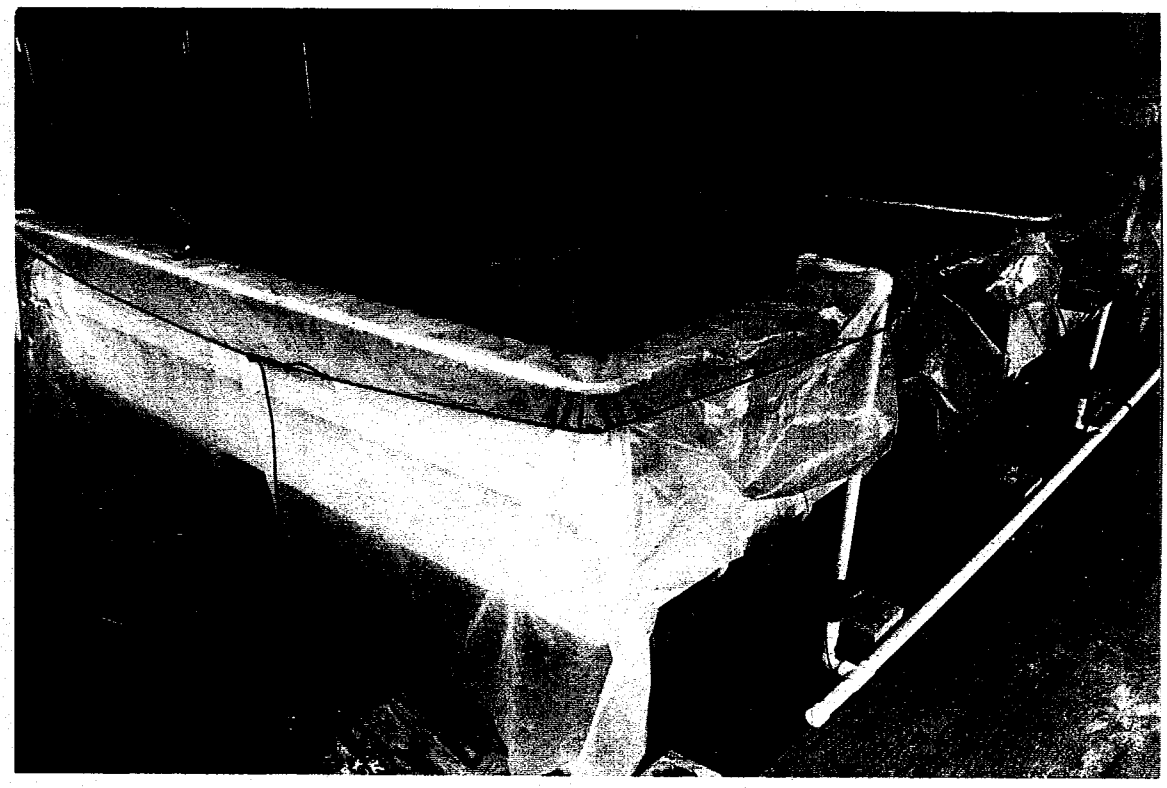

Plate 2. Durability Study Tanks.

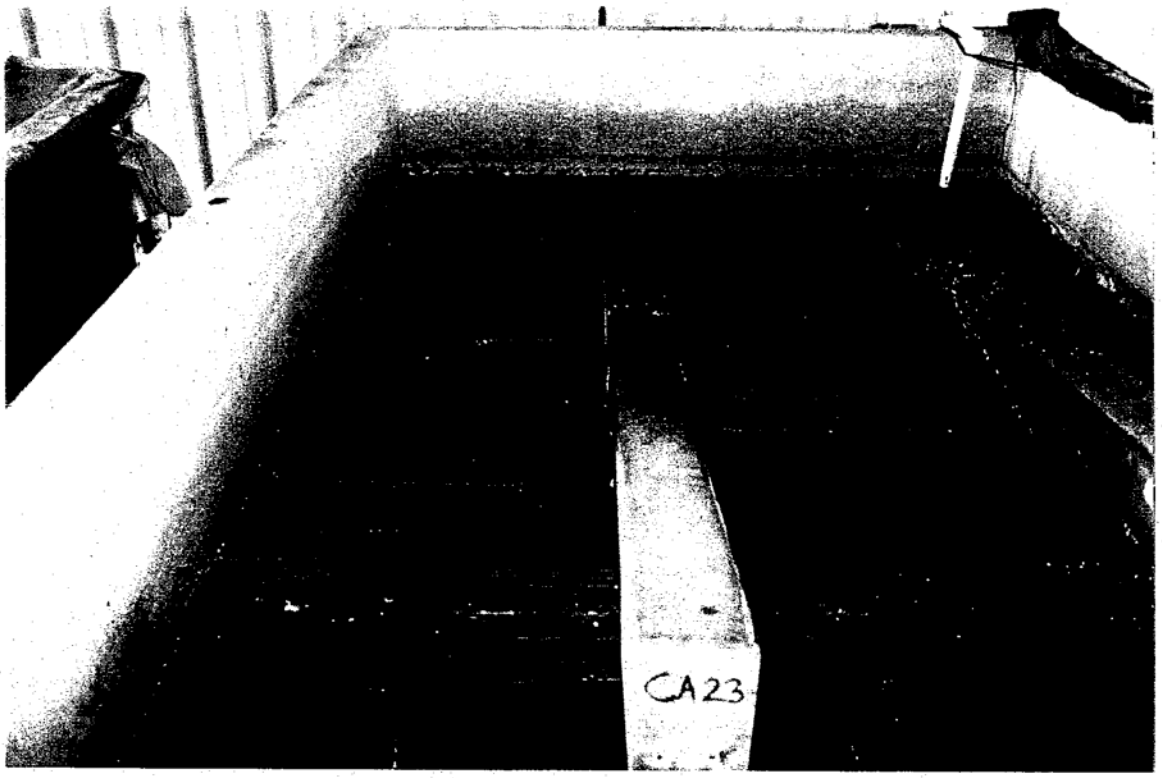

Plate 3. Low Tide.

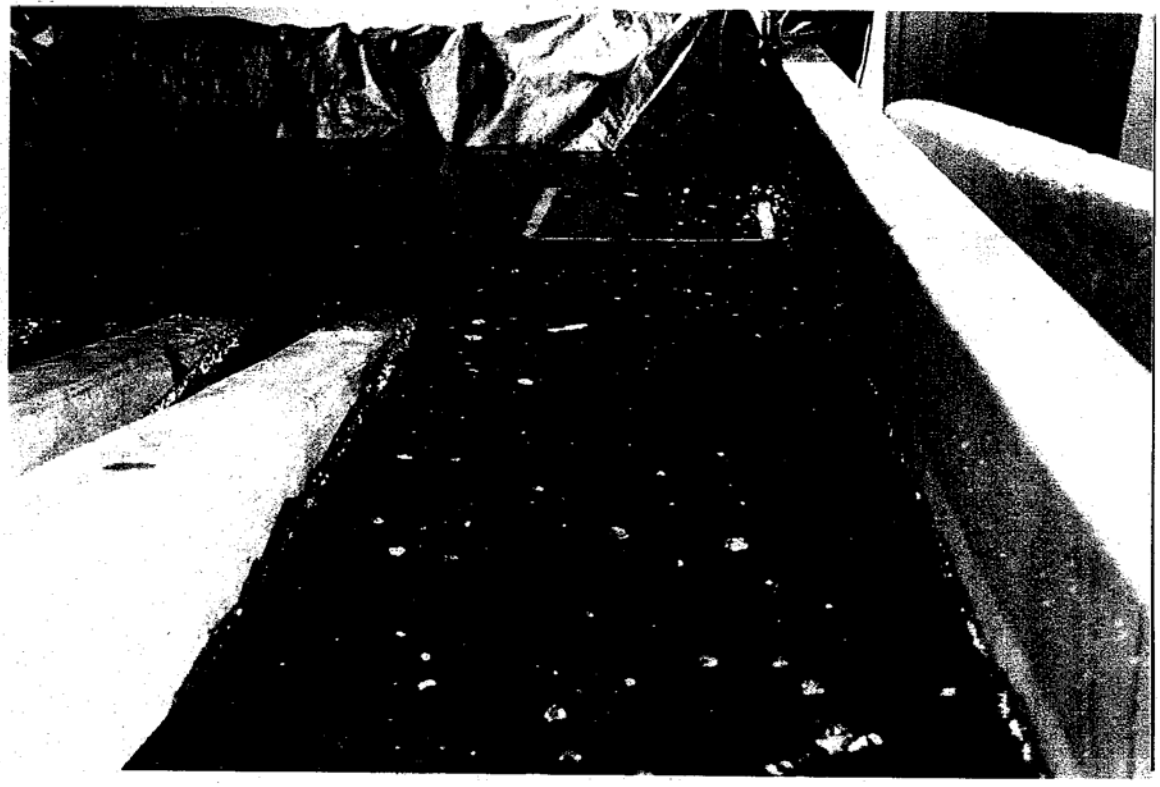

Plate 4. High Tide.

4. RESULTS

Following almost six months of exposure, relatively little deterioration was observed particularly in specimens that were initially free of defects. No deterioration was observed in the control specimens.

Only one specimen, FA2-3 exposed to thermal and tidal cycling showed some minor evidence of debonding. A blister formed in this specimen after approximately 6.5 weeks of exposure but subsequently stabilized to a size of about 2 in. x 0.4 in. Two other specimens, FAH2-3 and FAHP2-1 that were initially blemished, showed some increase in the de-bonded area. Plates 5-8 compare the state of the bond before and after exposure for specimens FA2-3 and FAH2-3. For the former, the debonded area is in the middle of the slab and cannot be seen. It can, however, be detected by tapping the region.

Among the seven durability study specimens, none of the six blemish-free specimens showed evidence of deterioration. However, for the one defective specimen (FAHP2-3), there was an increase in the extent of the original de-bonded area. A photograph comparing the specimen before and after exposure is shown in Plates 9-10.

For specimens exposed outdoors, there was no deterioration of the bond between epoxy and concrete. However, there was discoloration of the carbon fiber material in two specimens - MP2-4 and T2-1 (see Plates 11 and 12).

5. CONCLUSIONS

A total of nineteen specimens using five different epoxies and three different carbon fiber material were exposed to wet/dry cycles in salt water, thermal cycling and an outdoor environment. After almost 6 months of exposure, *very little damage could be discerned in the specimens that were originally free* of *defective workmanship. Only* one specimen, FA2-3,

initially free of blemish, developed localized de-bonding. In specimens with blemish, there was some increase in the extent of the defective area (see Plates 5-10).Two specimens exposed outdoors showed evidence of discoloration (see Plates 11 and 12).

The preliminary findings are very encouraging not only because of the satisfacatory performance of the epoxy bond in a harsh environment but also because five *different* epoxy systems proved to be adequate. With five competing systems, the price of epoxy is likely to remain competitive. More importantly, it suggests that highway structures repaired using carbon fabric or uni-directional carbon fiber material are likely to be able to withstand Florida's sub-tropical environment.

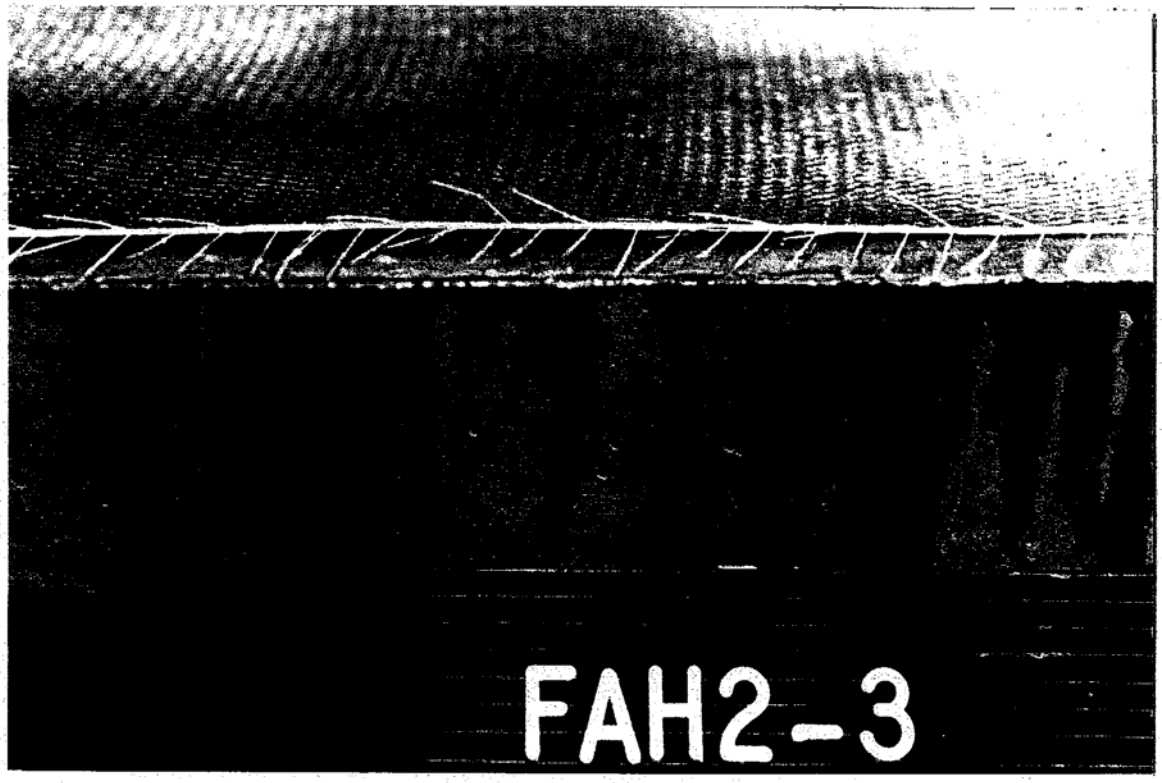

Plate 5. Defective Specimen in Bond Tank (as-received).

Plate 6. Same Specimen at End of Exposure.

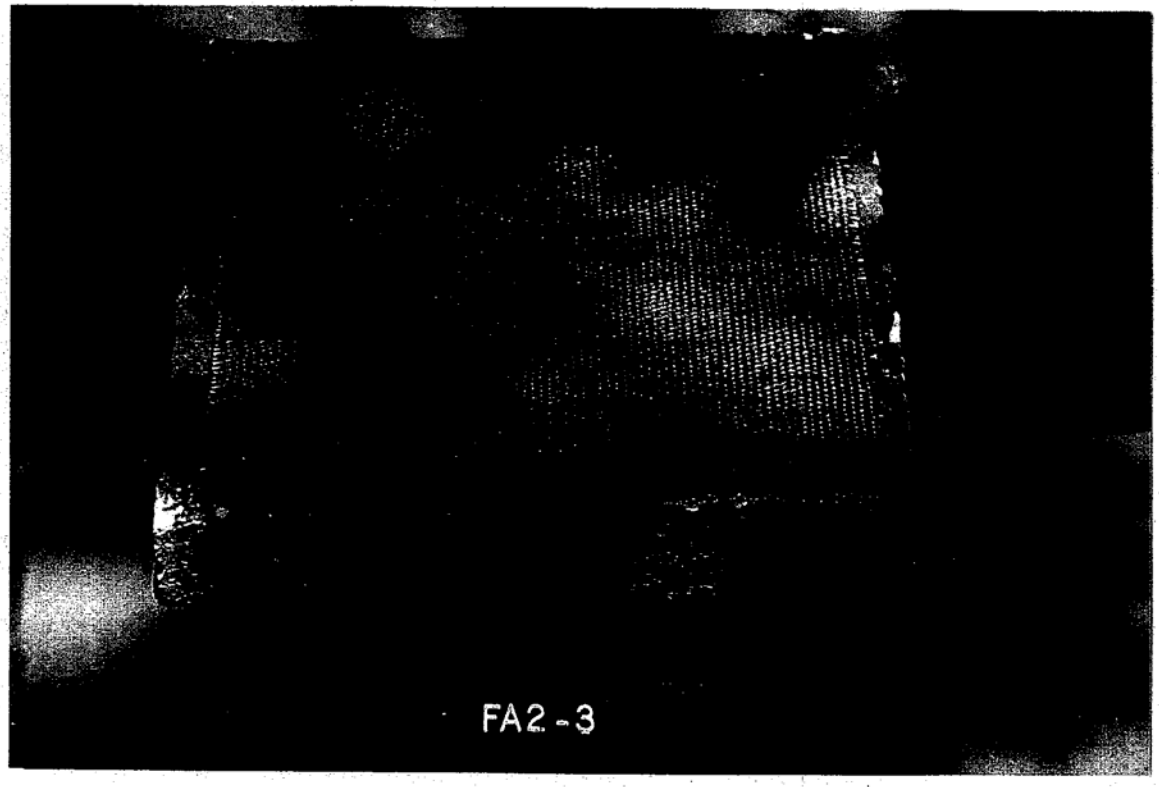

Plate 7. Specimen in Bond Tank (blemish-free).

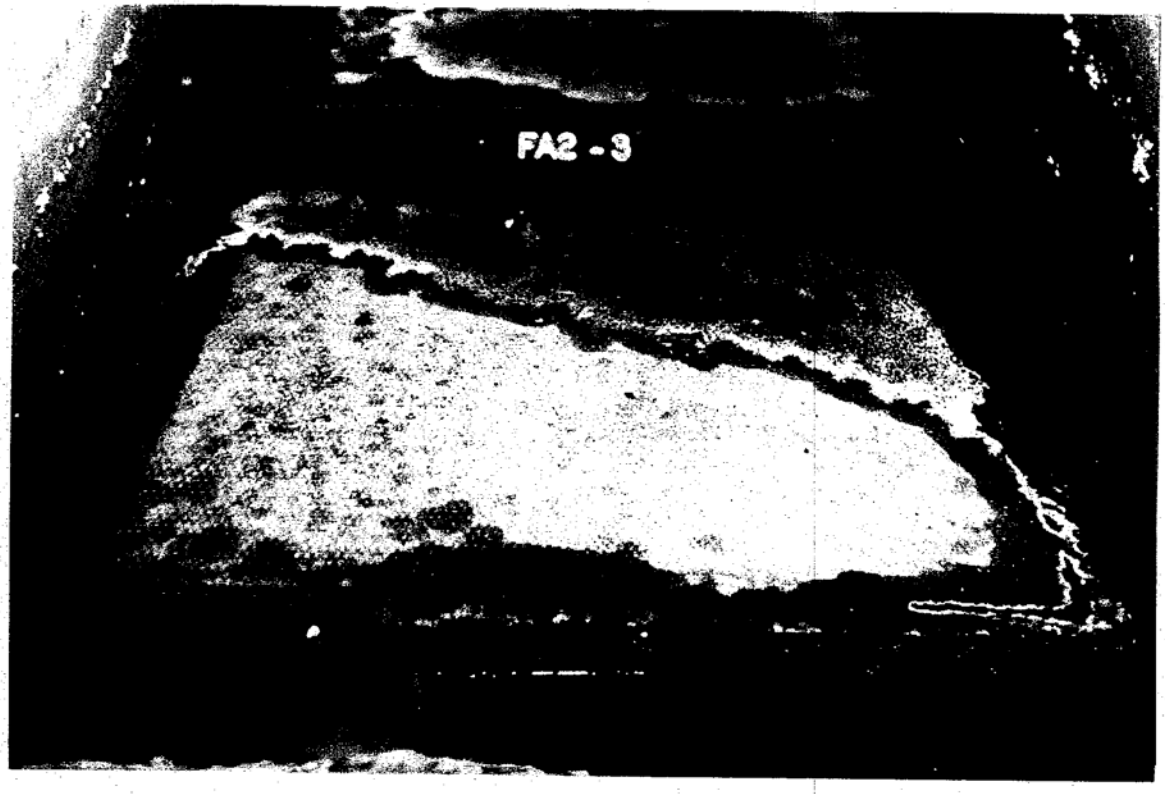

Plate 8. Same Specimen at End of Exposure.

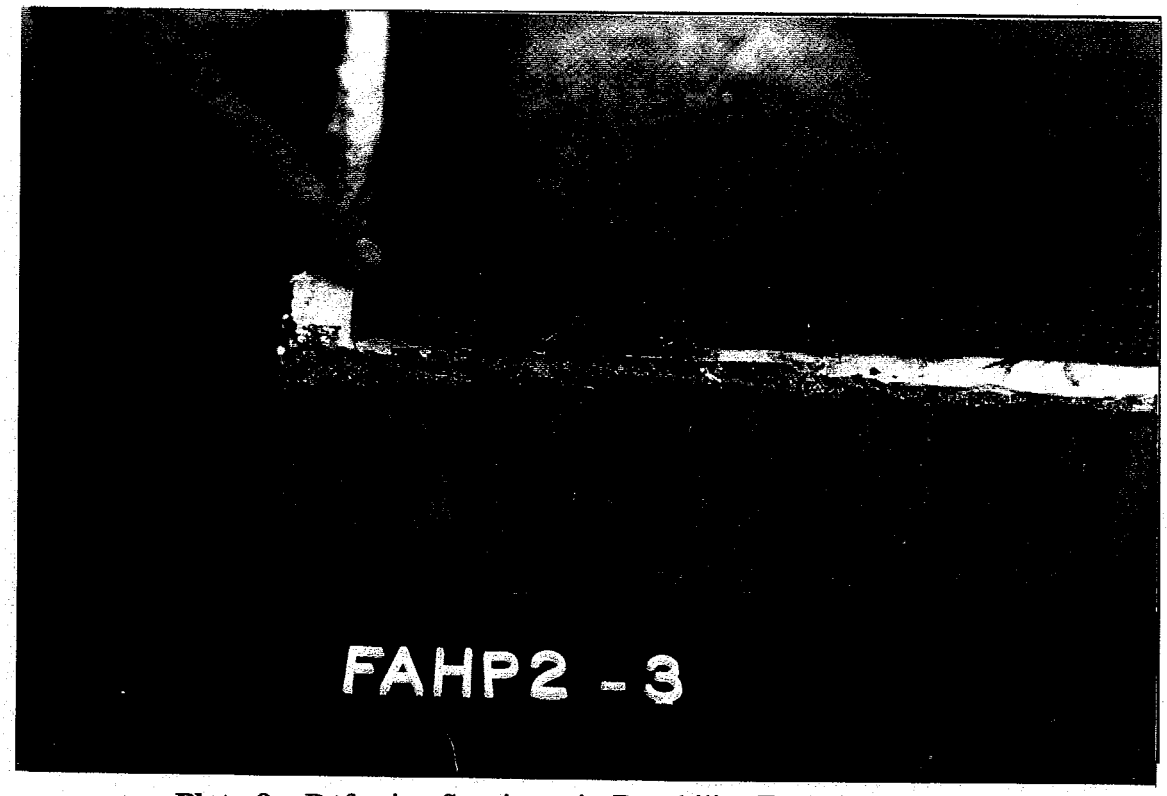

Plate 9. Defective Specimen in Durability Tank (as-received).

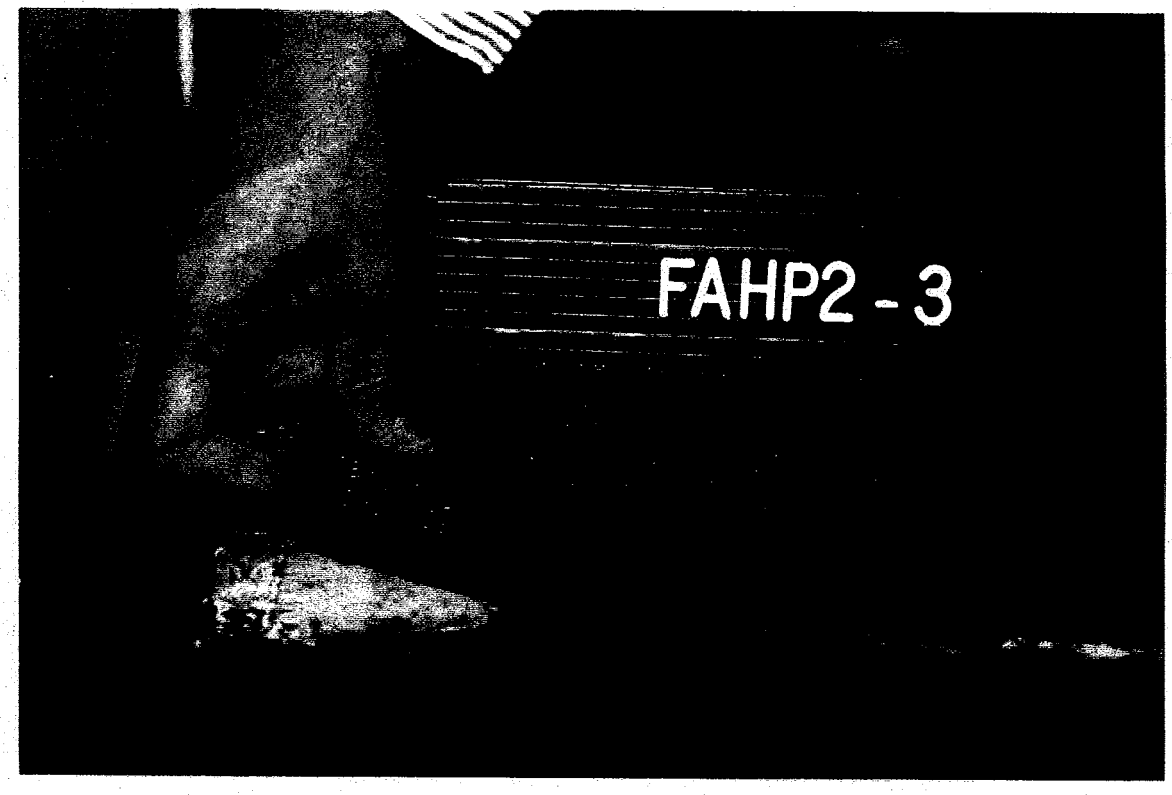

Plate 10. Same Specimen at End of Exposure.

Plate 11. Outdoor Set-up.

Plate 12. Discoloration of Outdoor Specimens.

APPENDIX A Bond Study
Temperature Data

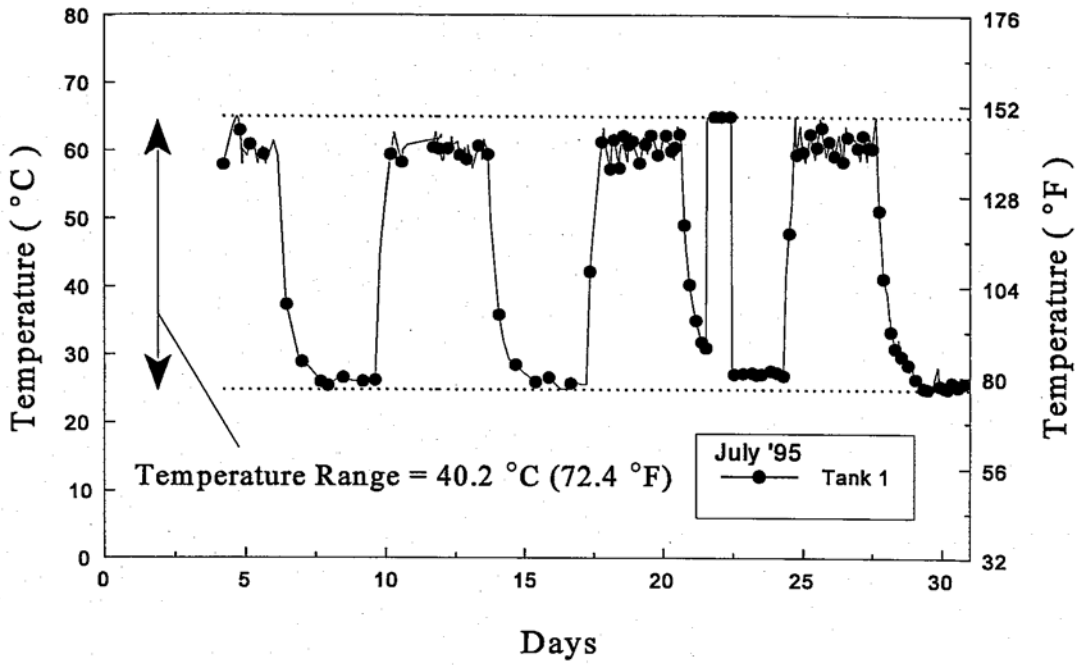

Figure A1. Temperature Cycle July '95 - Tank 1

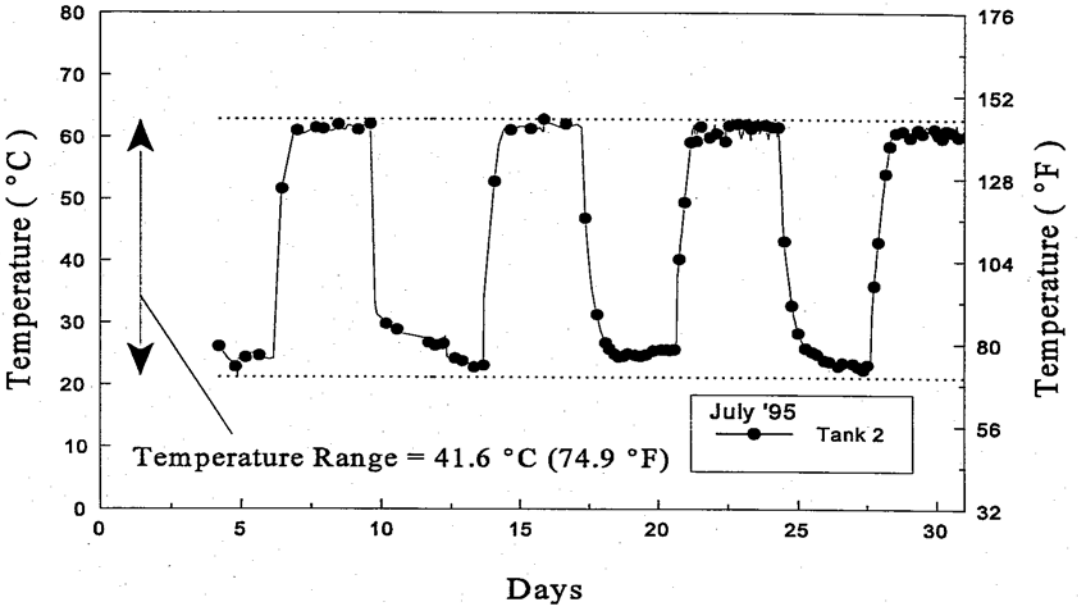

Figure A2. Temperature Cycle July '95 - Tank 2

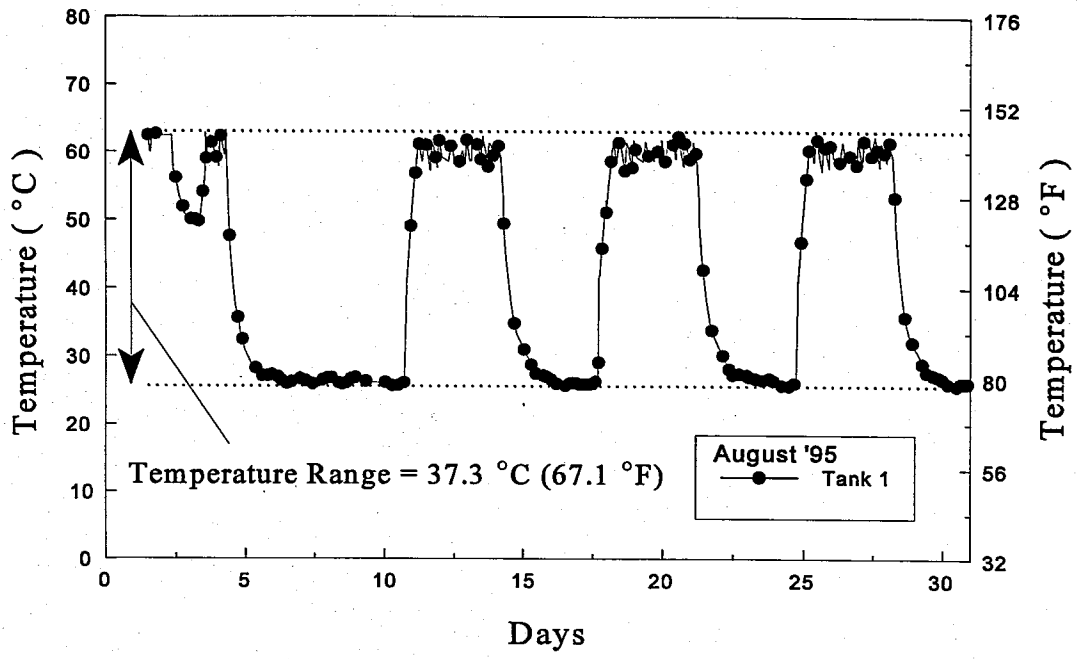

Figure A3. Temperature Cycle August '95 - Tank 1

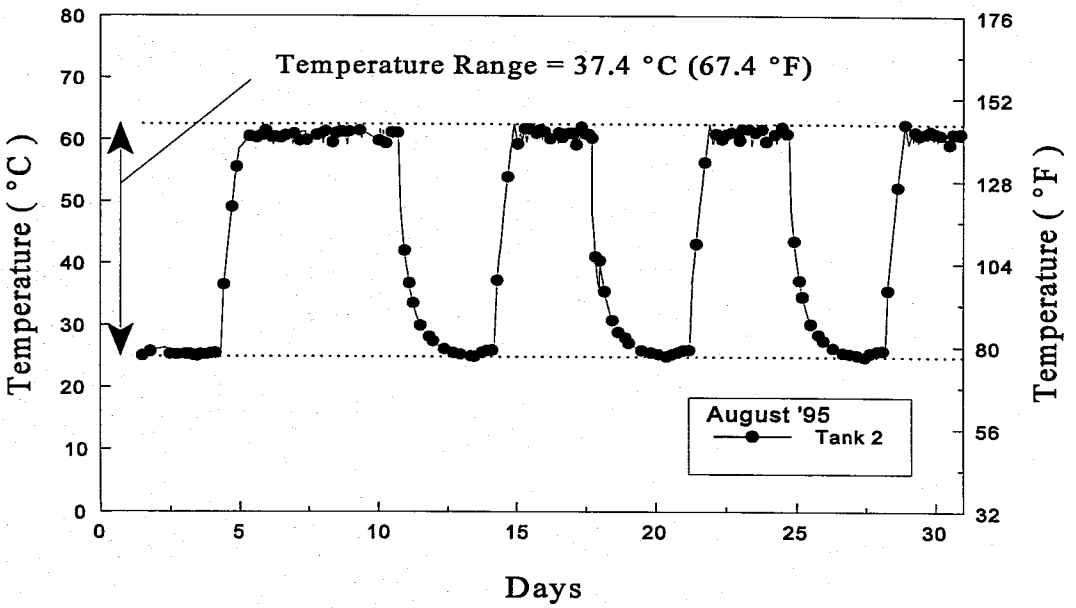

Figure A4. Temperature Cycle August '95 - Tank 2

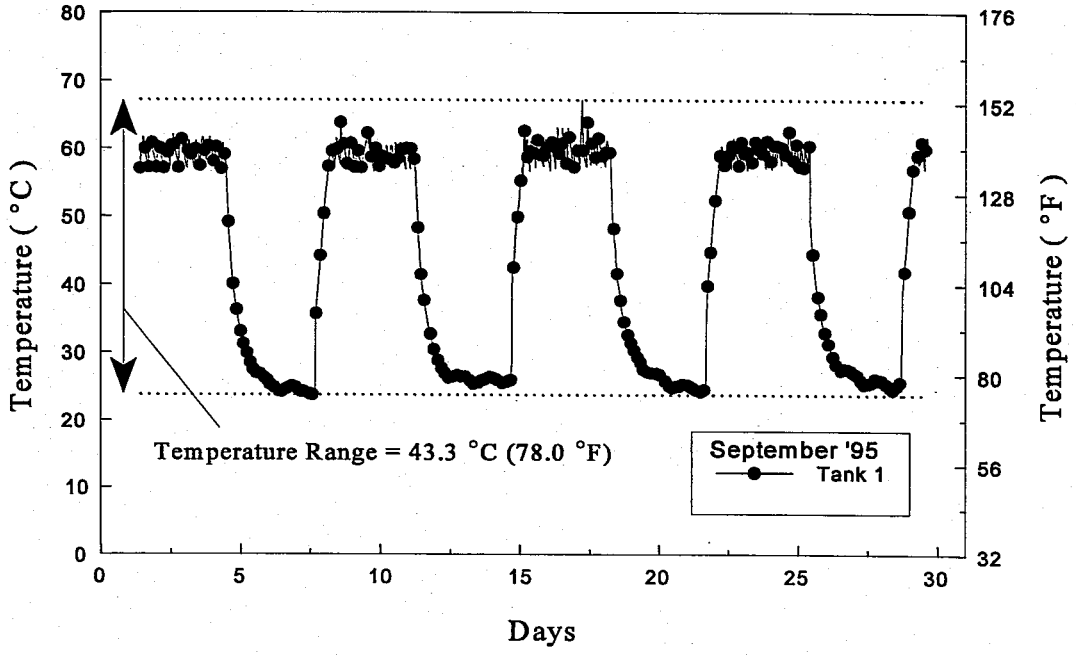

Figure A5. Temperature Cycle September '95 - Tank 1

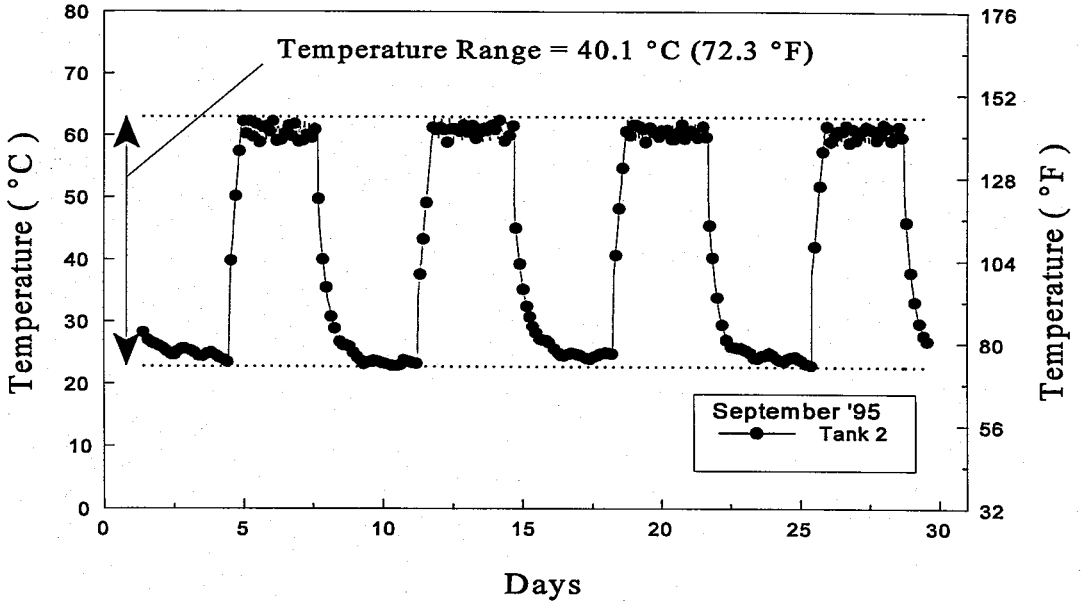

Figure A6. Temperature Cycle September '95 - Tank 2

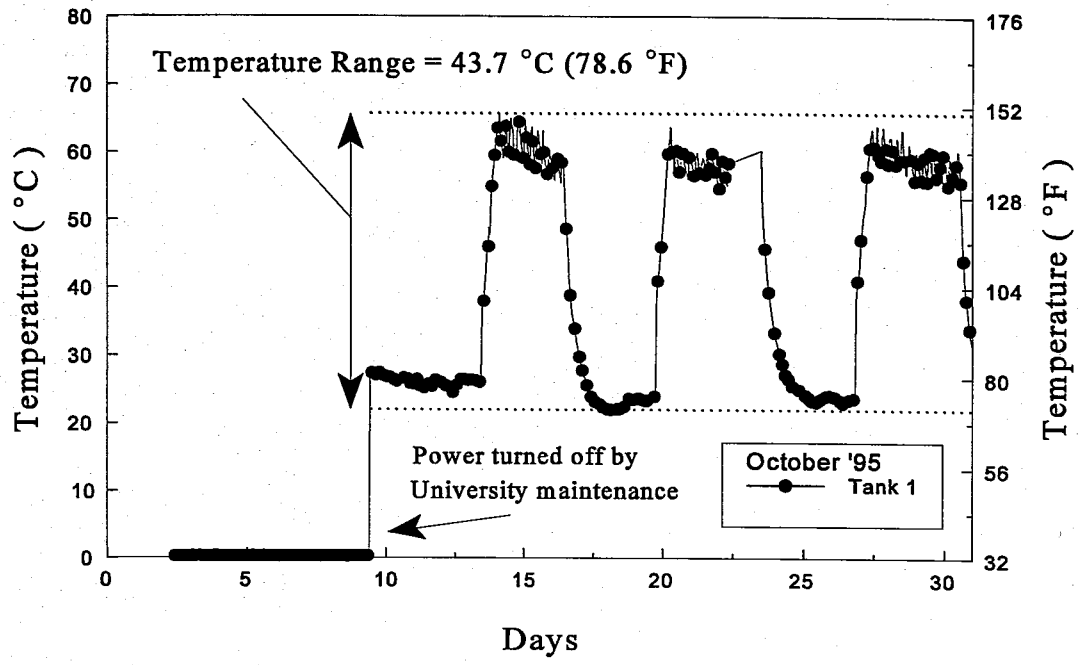

Figure A7. Temperature Cycle October '95 - Tank 1

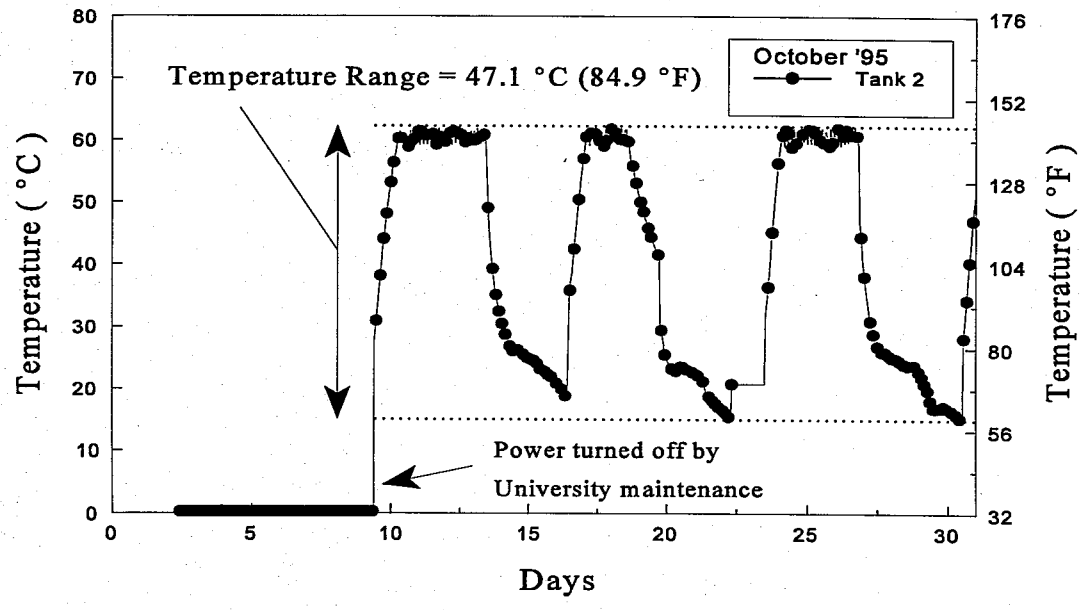

Figure A8. Temperature Cycle October '95 - Tank 2

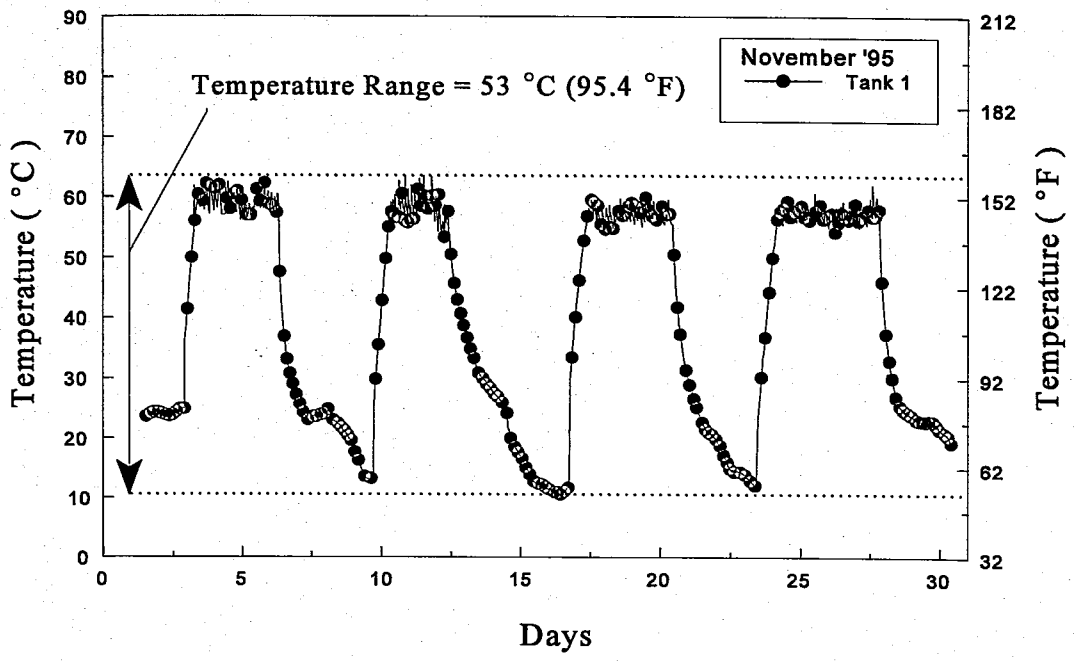

Figure A9. Temperature Cycle November '95 - Tank 1

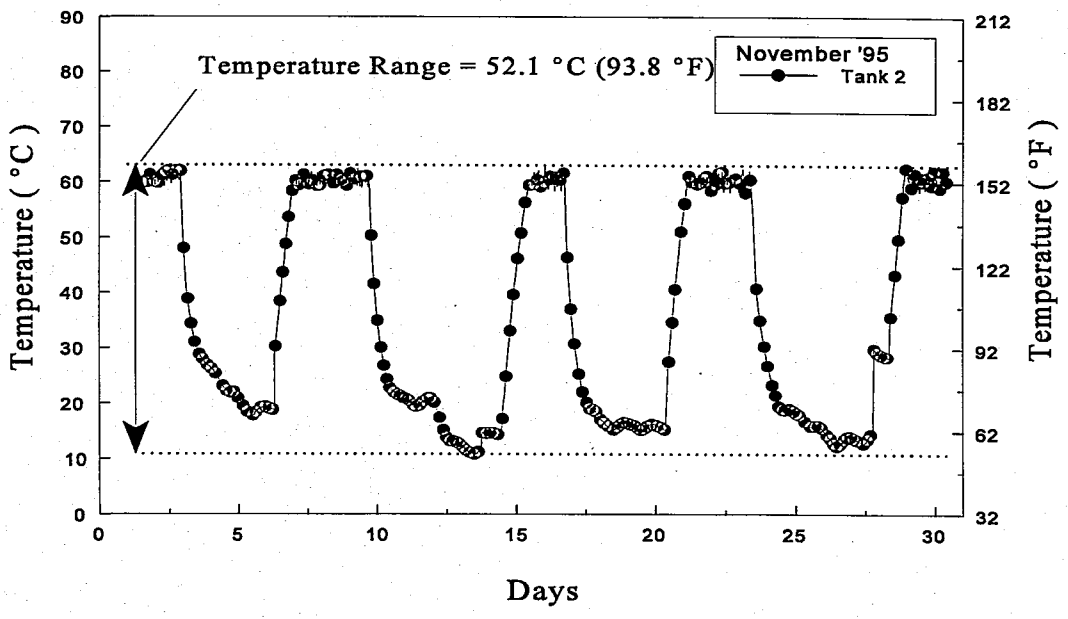

Figure A10. Temperature Cycle November '95 - Tank 2

APPENDIX B Durability Study
Temperature Data

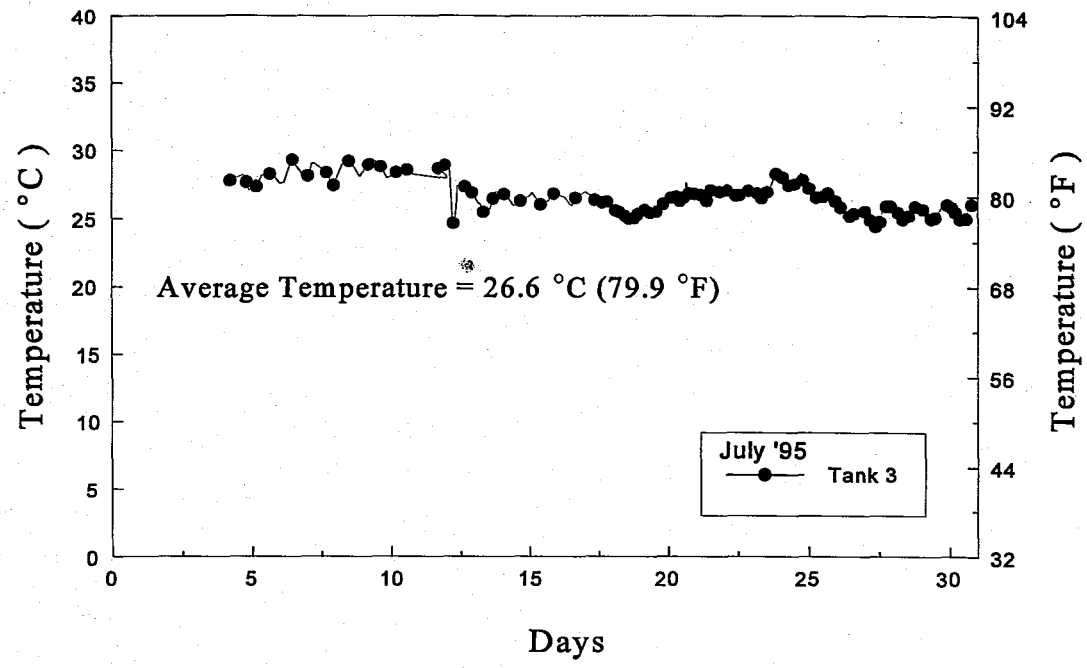

Figure B1. Temperature Cycle July '95 - Tank 3

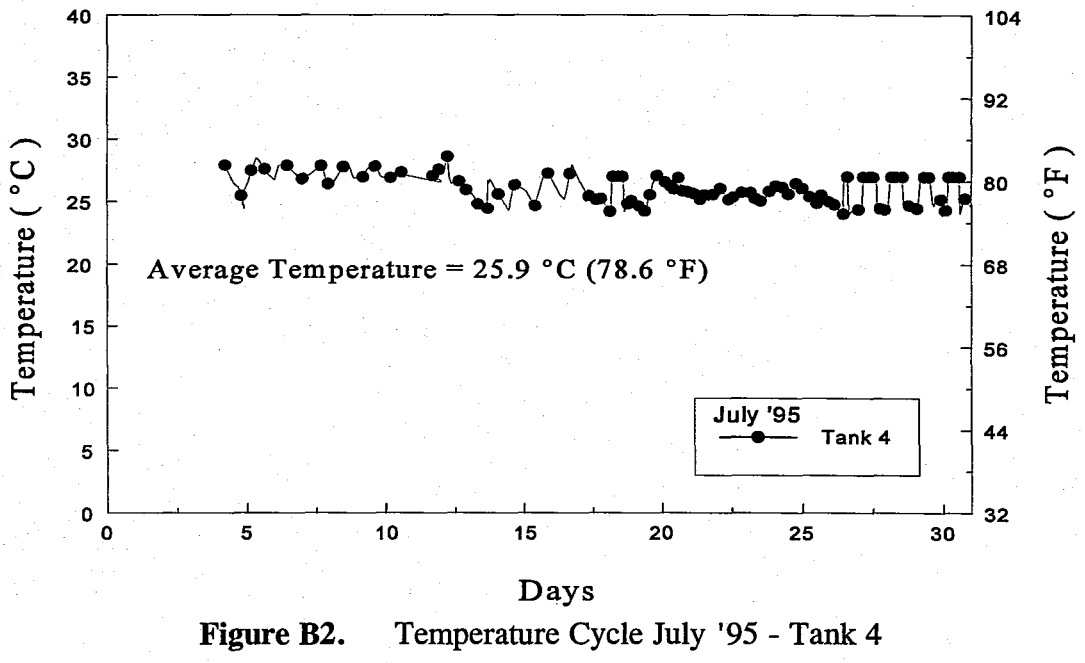

Figure B2. Temperature Cycle July '95 - Tank 4

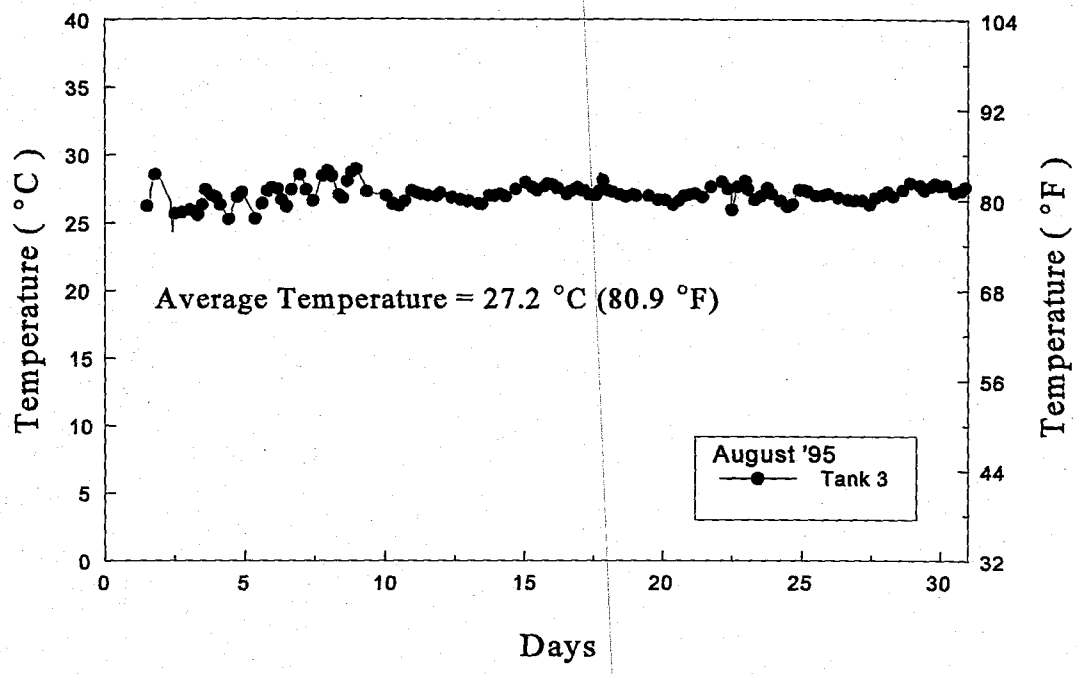

Figure B3. Temperature Cycle August '95 - Tank 3

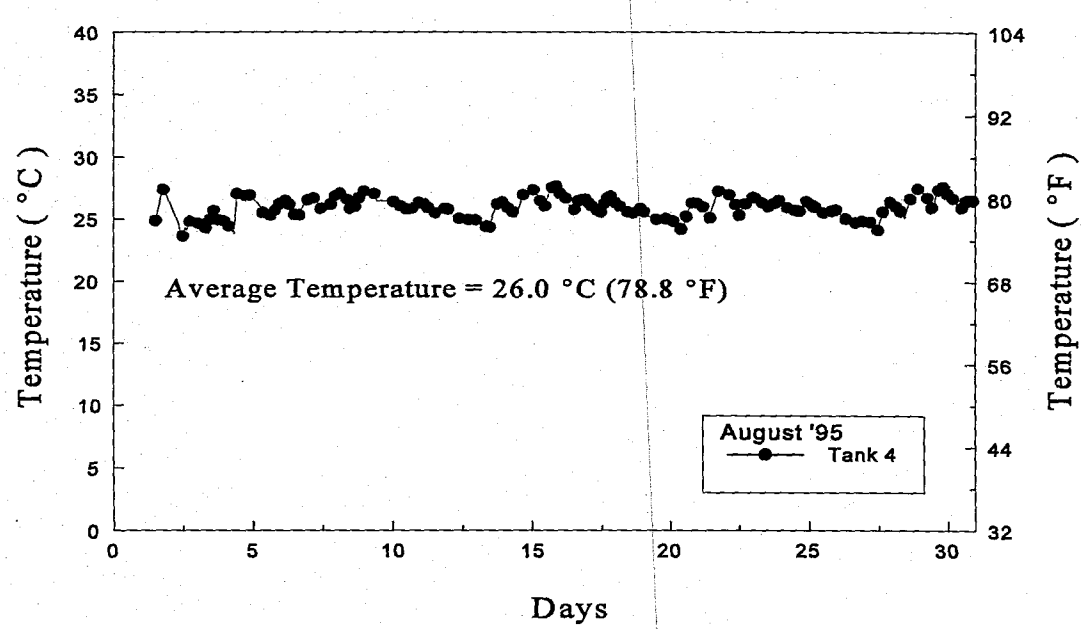

Figure B4. Temperature Cycle August '95 - Tank 4

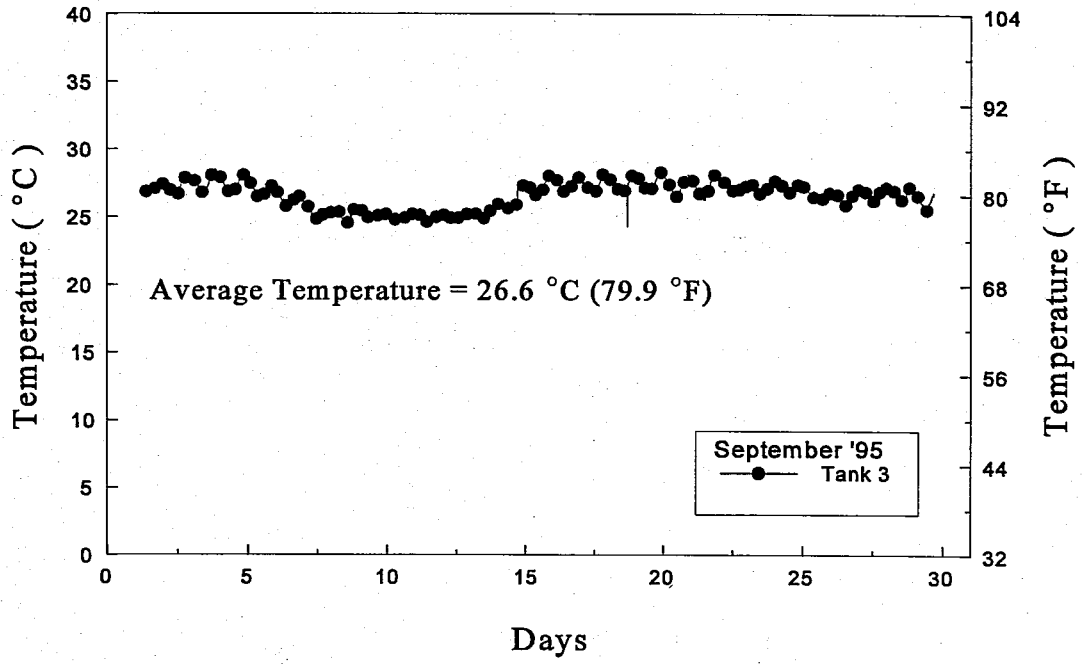

Figure B5. Temperature Cycle September '95 - Tank 3

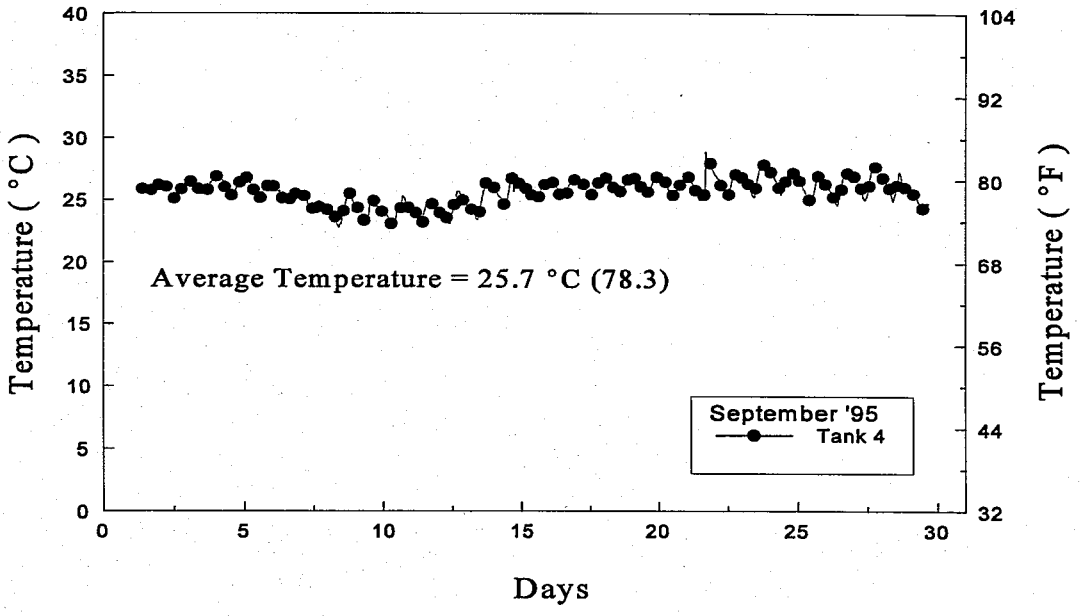

Figure B6. Temperature Cycle September '95 - Tank 4

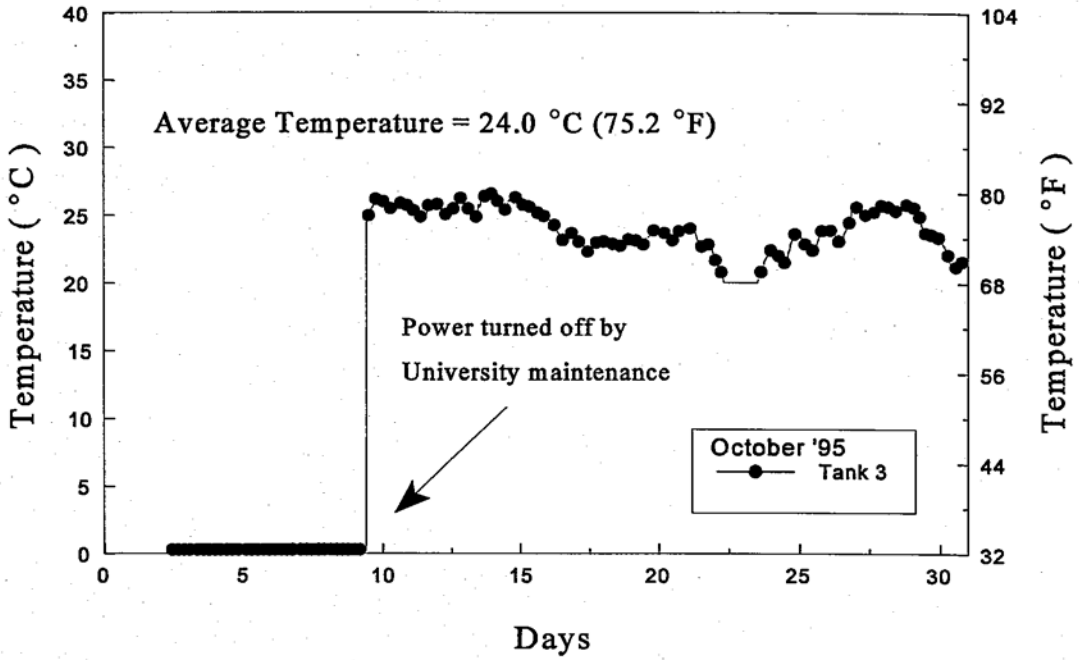

Figure B7. Temperature Cycle October '95 - Tank 3

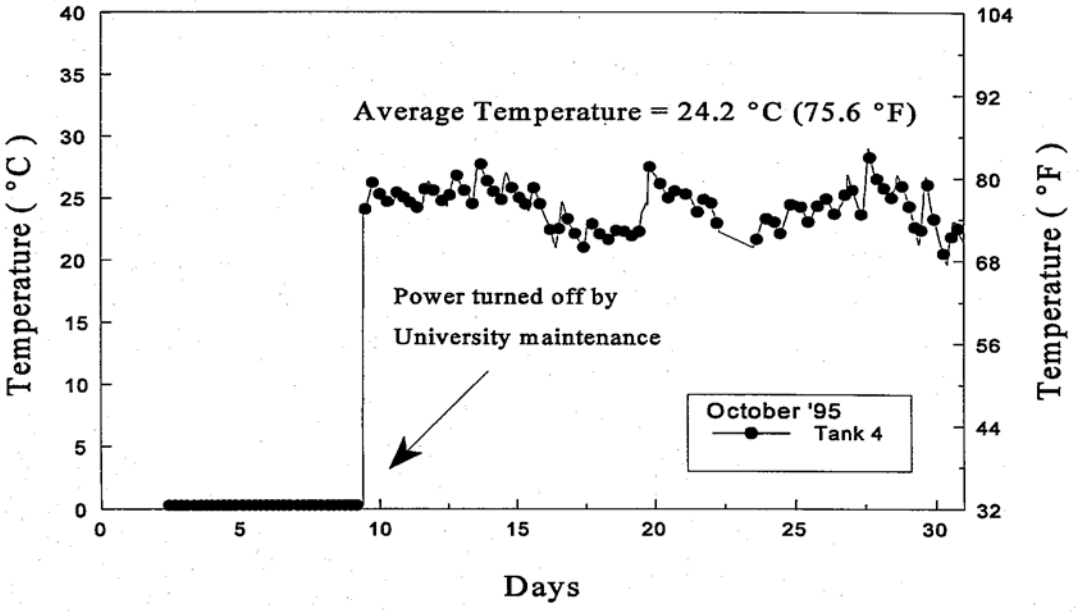

Figure B8. Temperature Cycle October '95 - Tank 4

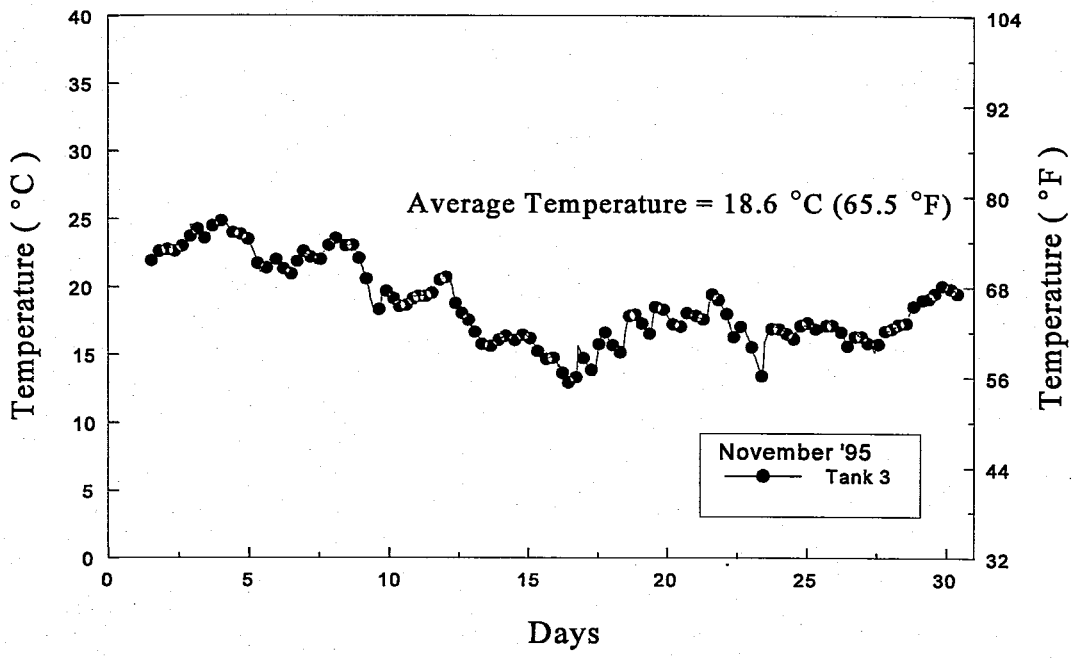

Figure B9. Temperature Cycle November '95 - Tank 3

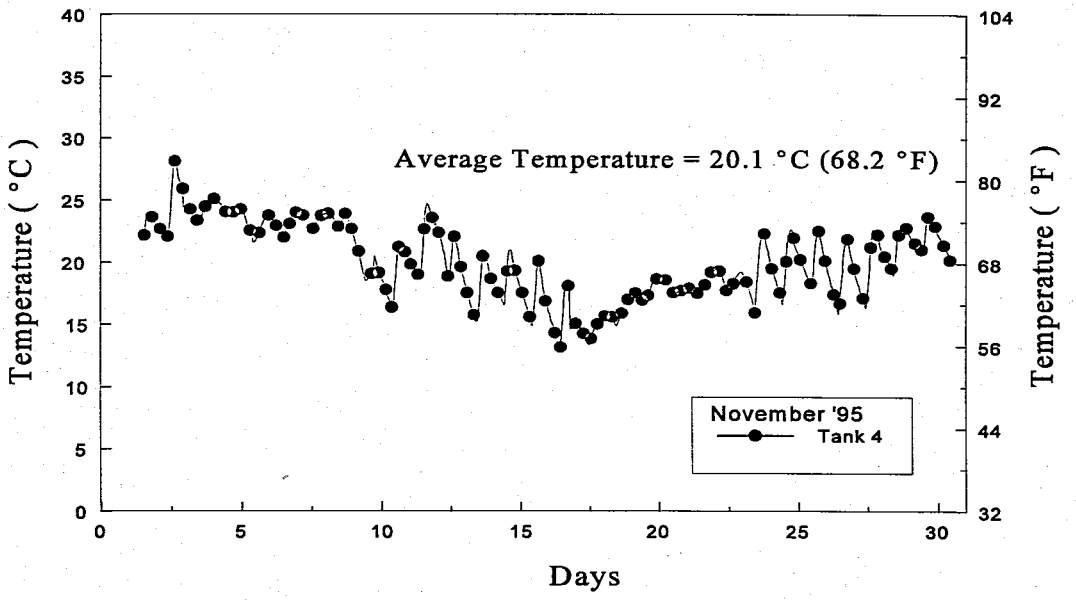

Figure B10. Temperature Cycle November '95 - Tank 4

APPENDIX C Outdoor Study
Temperature Data

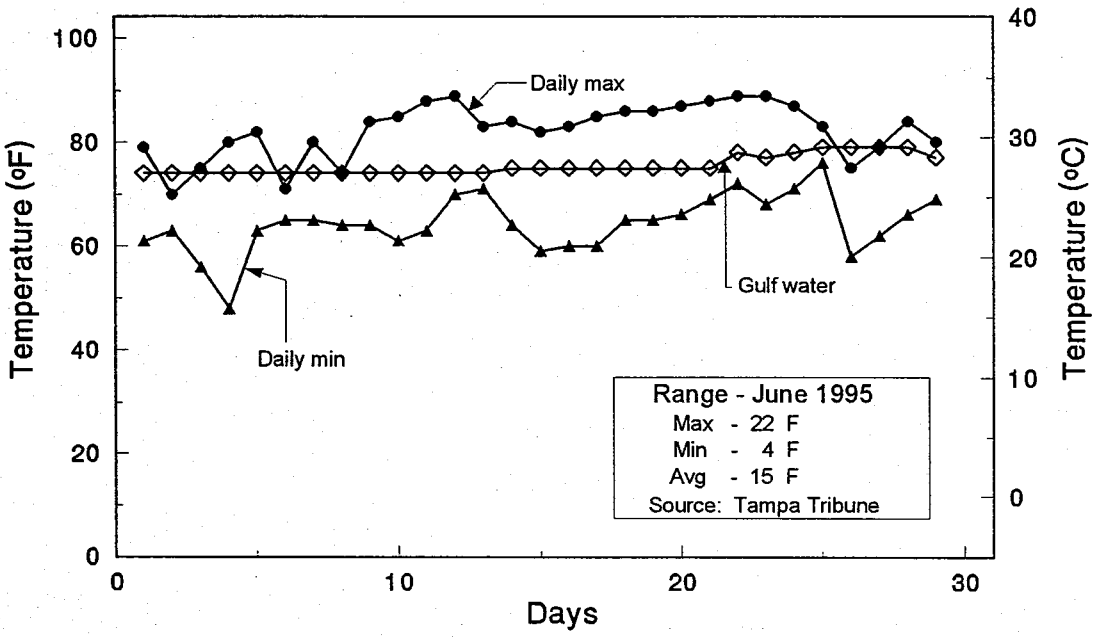

Figure C1. Temperature variation from Tampa Tribume

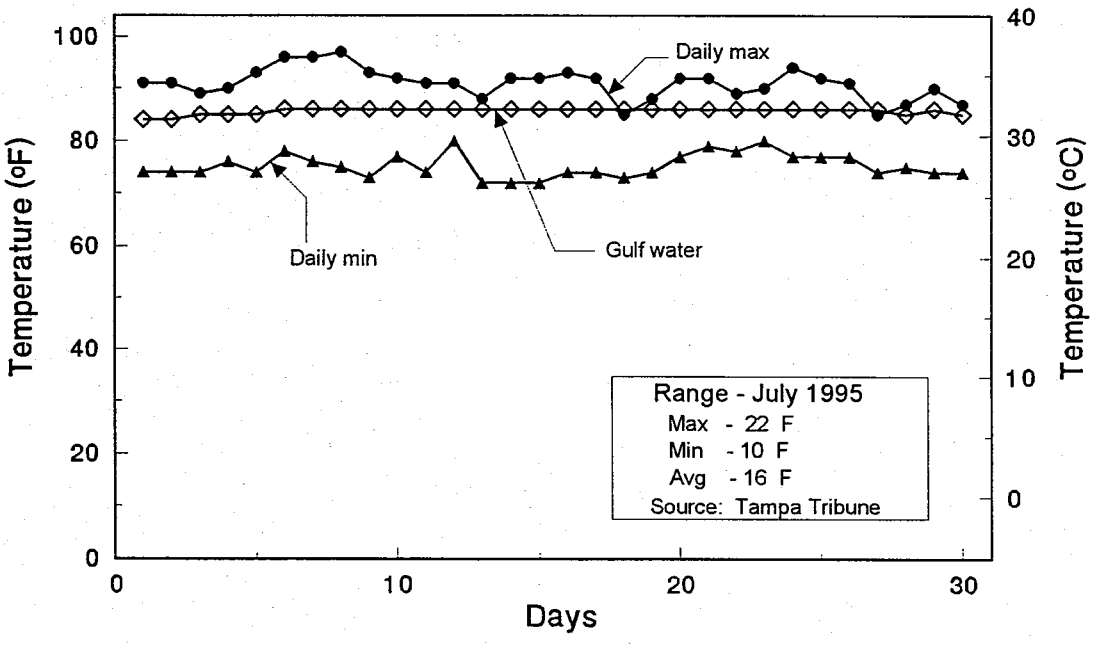

Figure C2. Temperature variation from Tampa Tribume

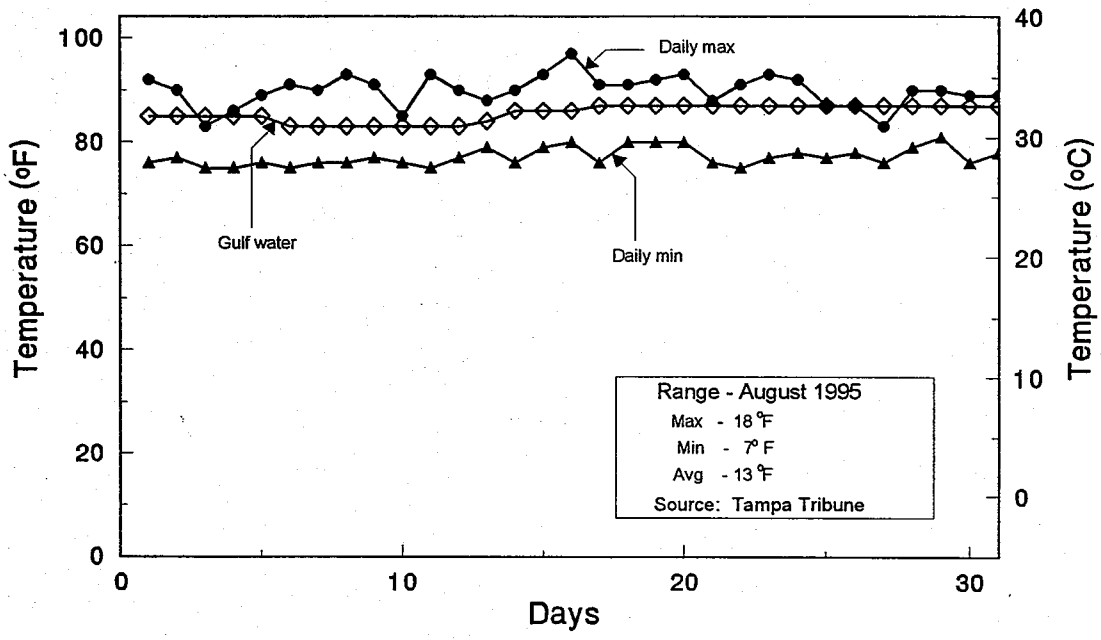

Figure C3. Temperature variation from Tampa Tribume

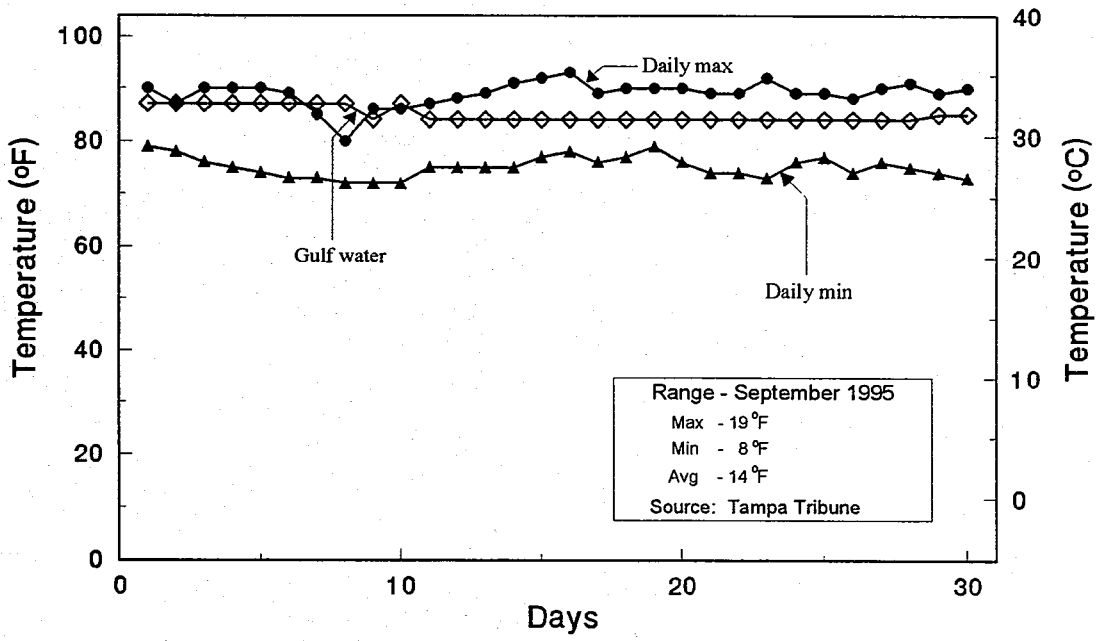

Figure C4. Temperature variation from Tampa Tribume

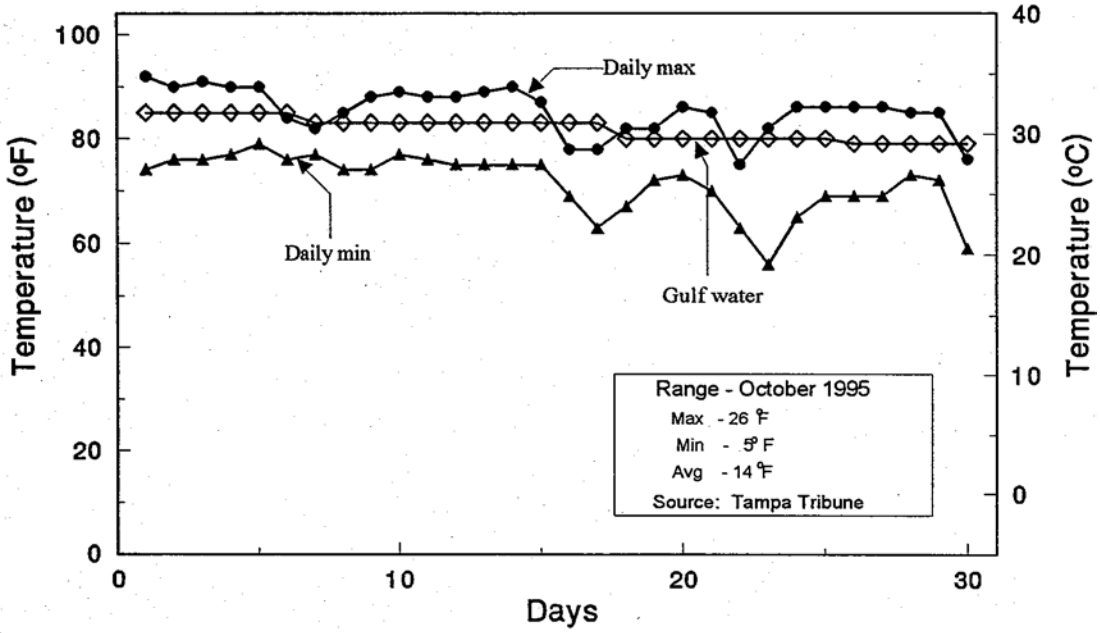

Figure C5. Temperature variation from Tampa Tribume

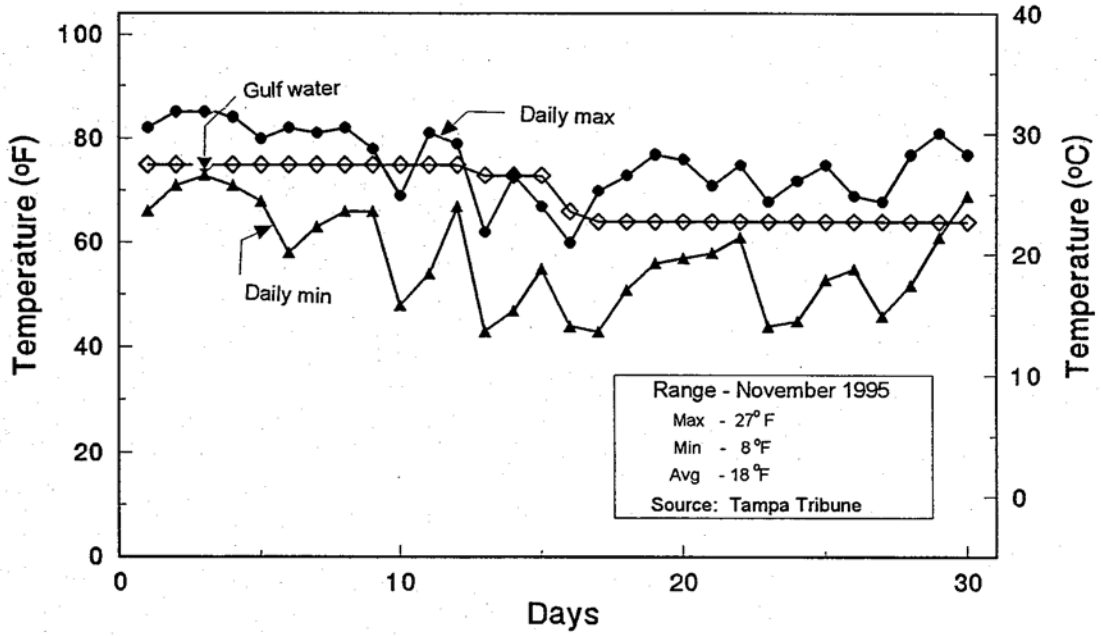

Figure C6. Temperature variation from Tampa Tribume