Concrete Maturity Testing in Michigan

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Introduction

Background

In the near future the Michigan Department of Transportation (MDOT) would like to develop a special provision that would allow contractors in the state to use concrete maturity testing to estimate the strength development of concrete pavements. To develop a specification MDOT was looking for a contractor and a suitable project in order to test the use of a possible wireless Concrete Maturity Monitoring System (CMMS). MDOT has experimented themselves with the use of a CMMS on a couple select projects around the state. The CMMS was not used as a full scale testing system on any of their selected projects.

Forming a partnership MDOT and Tony Angelo Cement Construction Company of Novi, Michigan began a study in May of 2003 to test the use of a CMMS on a project in Michigan.

Objectives

The objectives of this study were the following:

1. Use a Wireless Concrete Maturity Monitoring System (CMMS) on a project in Michigan from the beginning to the end of the project to monitor the strength gain of the concrete in an effort to minimize traffic disruption while providing real time data.

2. To provide feedback to MDOT regarding the performance and use of a CMMS from the contractor point of view which would help in developing a possible specification allowing the use of concrete maturity testing.

The Maturity Concept

The maturity concept accounts for the combined effects of time and temperature on concrete strength development. The strength of a given concrete mixture that has been properly placed, consolidated, and cured, is a function of its age and temperatures history. The maturity represented by TTF (Temperature Time Factor for the Nurse-Saul) has been found to be the area under the curve created by Temperature (°C) vs. Time From Placement (hr). The Nurse-Saul equation is the following:

$$M(t)=\Sigma (Ta-To) \Delta t$$

Where:

$M(t)$ = Temperature-Time Factor (TTF) at time (t), degree-days or degree-hours

Δt = time interval, days or hours

Ta = average concrete temperature during time, °C or °F

To = datum temperature at which is assumed that concrete ceases to gain strength with time; the value of -10°C (14°F) is most commonly used.

The maturity concept has been around since the early 1950's. This is the most popular method for Maturity with state DOT's.

Maturity Device

The Concrete Maturity Monitoring System is a combination of technologies. There are three main components to it: 1) A radio frequency tag developed and patented by Identec Solutions of British Columbia, 2) Software developed by International Road Dynamics (IRD) of Saskatchewan, 3) A portable (in our study we used a Compaq iPAQ) hand held device which contains a PCMCIA card. The system is marketed by WAKE, Inc. of Sturgis, Michigan, the US distributor. One of the tags is shown in figure 1.

Figure 1 Identec Solutions IQ8T Tag

The i-Q8T tag has the ability to capture the ambient temperature and store it within its memory. The tag is 5 1/8” long, 1 1/16” wide and 7/8” high and weighs 1.75 ounces. It contains a temperature sensor, memory storage of 8Kb, a battery with a 5-year life and the ability to transmit radio signals. The i-Q8T will record the temperature at set intervals as specified by the user. For this study the default setting of 30 minutes was used. The i-Q8T stores 1024 data points in the tag memory and operates at 915 MHz. It can be read from a distance of over 300 feet in clear air, but buried in 5’ to 8” of concrete, its range is about 20’ with the unit we had.

The software developed by IRD is called Pocket Concrete and will work on portable hand held-devices that use Microsoft’s Pocket PC operating system, the unit must have the capability to accept a PCMCIA card. As we used the Compaq iPAQ, Compaq (now owned by Hewlett Packard) has an expansion pack attached to its back which can hold the PCMCIA card. See figure 2 for a picture of the iPAQ. In the iPAQ we used, the PCMCIA card contains a connection for a small quarter-wave antenna to be plugged in.

Figure 2 Compaq IPAQ Pocket PC

The combination of the technologies we used is called Radio Frequency Identification (RFID). The antenna emits radio signals which activate the tag and allows the user to read or write to the tags as well as pass commands along to it. The transceiver is located in the PCMCIA card which is connected to the iPAQ unit. The IRD Pocket Concrete Software uses the in-situ concrete temperature along with either the Nurse-Saul equation or the Arrhenius method for calculating maturity. The Pocket Concrete Software exports to a comma-separated file that can be used by Excel. The software exports the following information:

- Tag ID
- Location of Tag
- Logging Interval
- Pour Time and Date
- End of Recording Time and Date

- Sample Count
- Average Temperature
- High Temperature
- Low Temperature
- Chronological Age
- TTF
- Strength

Why the Wireless Concrete Maturity Monitoring System (CMMS)

The CMMS was the right unit for this study for multiple reasons. The main reason why the CMMS was the best for this study and potential future MDOT projects is the fact that it is wireless. The system operates without any wires coming out from the concrete slab or wires that have to be buried at the time of placement. This system also operates without a data collection system being left in the field that is reading data from some device in the concrete. The construction environment is harsh and any system that would be left in the field may not be there the next day or in its original condition. The CMMS is also less labor intensive to position in the field. The tag is placed into the concrete and ready for use, other systems require the burying of wires that must be placed coming out of the concrete. Upon seeing that a wireless concrete maturity system is available why would one want to use a system with wires?

Building the Curves for Maturity

In order for the maturity concept to work one must have a known curve for the mix design that is being tested in the field. The curve which is a plot of strength vs. TTF is created by making cylinders or beams and breaking them while recording the TTF in at least one of the specimens. The maturity concept can be applied by using either compressive strength cylinders or flexural strength beams. The concrete in order to make the test specimens for the curve should come from a batch of 4 cubic yards or greater. On this study, compressive strength cylinders were used since the cylinders were easier to make and a testing lab was located on the project.

On May 21, 2003 at the Woodcreek Farms Subdivision #3 in Flat Rock, Michigan, concrete was produced for testing in order to make two maturity curves by a concrete plant operated by Tony Angelo Cement Construction Company. The first curve was intended for Slipform Concrete and the second curve was intended for Handwork. The concrete for the testing came from two 8 cubic yard loads. Shown in Figure 3 are the mix designs for Mix#1 Slipform and Mix#2 Handwork.

Material	Type/Supplier	Mix #1 Slipform SSD, Weight Lbs	Mix#2 Handwork SSD, Weight Lbs
Cement:	Holcim Type I Dundee	342	342
GGBFS	Holcim Grancem 100	185	185
Fine Aggregate	2NS Levy New Hudson MDOT #63-48	1516	1471
Coarse Aggregate	6AA BFS Levy Dix MDOT #82-19	1421	1461
Water	Local	245	245
Air Entertainer	W.R. Grace Daravair 1400	1.0 oz/cwt	1.0 oz/cwt
Water Reducer	W.R. Grace WRDA 20	3.0 oz/cwt	
Mid-Range Water Reducer	W.R. Grace Daracem 65		6.0 oz/cwt
28 Day Strength (psi)		3500	3500
% Replacement		35%	35%
Slump (inches)		0-3”	Max 6”
Air Content		6.5% +/- 1.5 %	6.5% +/- 1.5 %

Figure 3 Mix Designs for Mix#1 and #2

The concrete for the two mixes was tested for slump, air, and temperature prior to making 20 cylinders for each mix design. The field test results for both mix designs are shown in Figure 4.

	Mix #1 Slipform	Mix #2 Handwork
Time	11:28 P.M.	11:44 P.M.
Slump	2.25 inches	3.75 inches
Air Temp	58°F	58°F
Concrete Temp	64°	64°F
Air Content	6.0 %	6.0 %

Figure 4 Field Data for Mix Designs

Two of the cylinders in each set of 20 had an IQ8T tag placed into it. The tag was placed into the center of the cylinder at mid depth. In Figure 5 is a picture showing the tags placed into the cylinders.

Figure 5 IQ8T Tags placed in cylinders

The cylinders were cured in the field until being picked up for delivery to the testing lab. An IQ8T tag was also placed on nearby tree in order to monitor the ambient air temperature near the concrete cylinders. 18 of the 20 cylinders in each mix were then broken by SME of Plymouth, Michigan. Prior to transporting the cylinders to the testing lab a reading was made on all four of the tags that were in place in the cylinders. The TTF of the cylinders was recorded for each of the cylinder breaks. Figure 6 shows the cylinder break schedule for all 18 cylinders per mix. The cylinders of the two mix designs were broken on the same schedule. Additionally, anytime a cylinder break occurred three cylinders were broken.

Cylinders #1-3	24 hours	1 day
Cylinders #4-6	48 hours	2 day
Cylinders #7-9	72 hours	3 day
Cylinders #10-12	120 hours	5 day
Cylinders #13-15	168 hours	7 day
Cylinders #16-18	672 hours	28 day

Figure 6 Concrete Cylinder Break Schedule

From the cylinder breaks and the TTF readings the following two maturity curves shown in figure 7 were created. The data points have been fitted with a polynomial trend line.

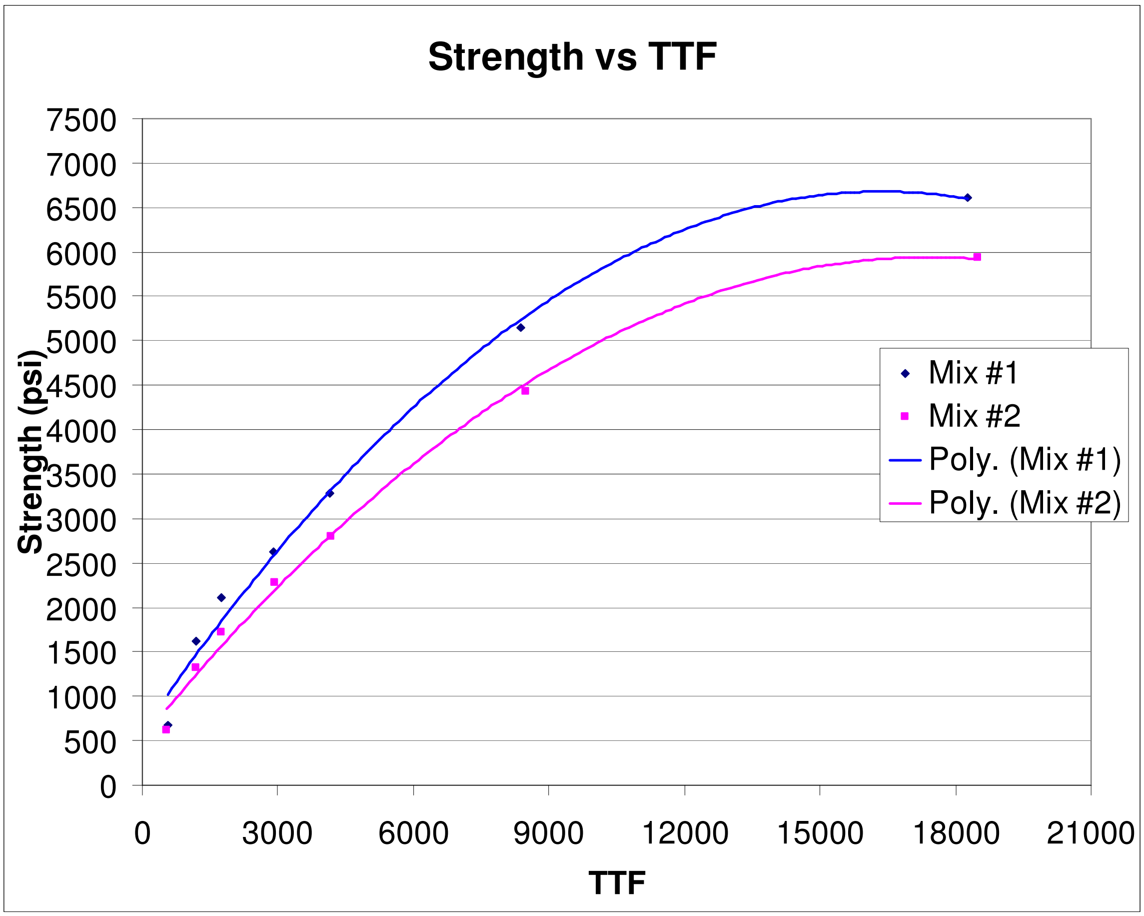

Figure 7 Maturity Curves for Mix#1 and Mix#2

The table in figure 8 shows the TTF readings and cylinders breaks used to make the curves in figure 7

Age (Days)	Mix #1 TTF	Mix # 1 Comp Strength (psi)	Mix #2 TTF	Mix #2 Comp. Strength (psi)
1	553	667	533	610
2	1191	1620	1170	1313
3	1753	2107	1739	1717
5	2910	2630	2920	2275
7	4136	3280	4167	2795
14	8383	5145	8493	4435
28	18265	6615	18490	5935

Figure 8 TTF reading and Compressive Strength for Mix#1 and Mix#2

Shown in figures 9 and 10 are the Time vs. Temperature Curves for Mix# 1 and #2. The curves show the tags that were placed into Cylinders #19 and #20 for both mixes as well as the ambient air temperature. The curves also show that little variation was found between the tags in Mix#1 and Mix#2.

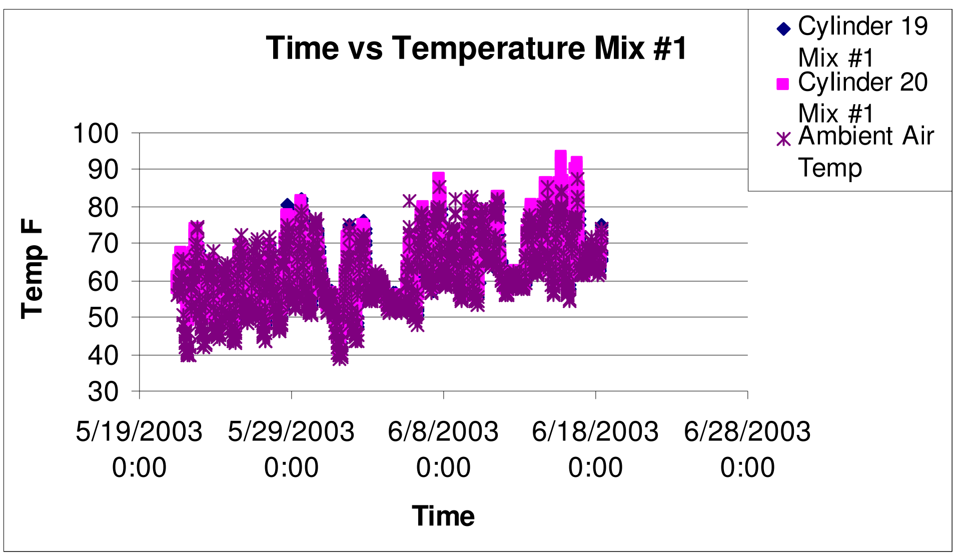

Figure 9 Time vs. Temperature for Mix #1 Slipform

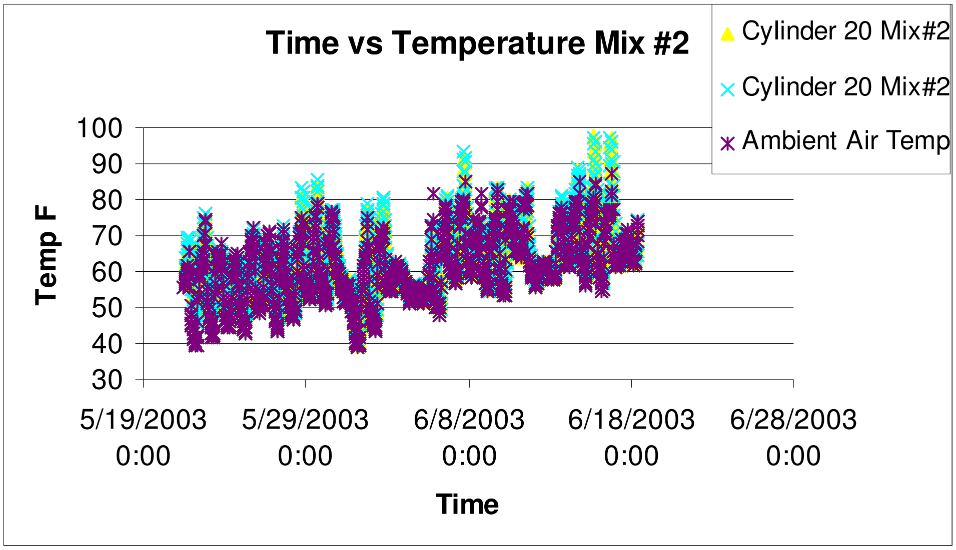

Figure 10 Time vs. Temperature for Mix #2 Handwork

Test Site Location

The test site for the wireless concrete maturity system was Grand River Avenue from Beck Road to Lanny's Road in the City of Novi, Oakland County, Michigan. This project was MDOT project# BE01-63522-57922A. The owner of the project is the Road Commission for Oakland County. The project was designed and inspected by JCK and Associates of Novi, Michigan. The project involved removing the existing two lane concrete road which had been overlaid with asphalt and replacing it with a five lane concrete road with separate concrete curb and gutter. The 1.6 mile project was lined with over 40 businesses that were impacted by this project. The complexity of the job was increased by the type of business in this area, for example a transit mix concrete company, a sand and gravel hauling company, an automotive supplier that runs multiple shifts. This project was constructed concurrently with the reconstruction of the Grand River Bridge over the CSX Railroad which is located at the east end of the project. Shown in Figure 11 is a location map of study location. The segment of road in orange used the IRD wireless concrete maturity system.

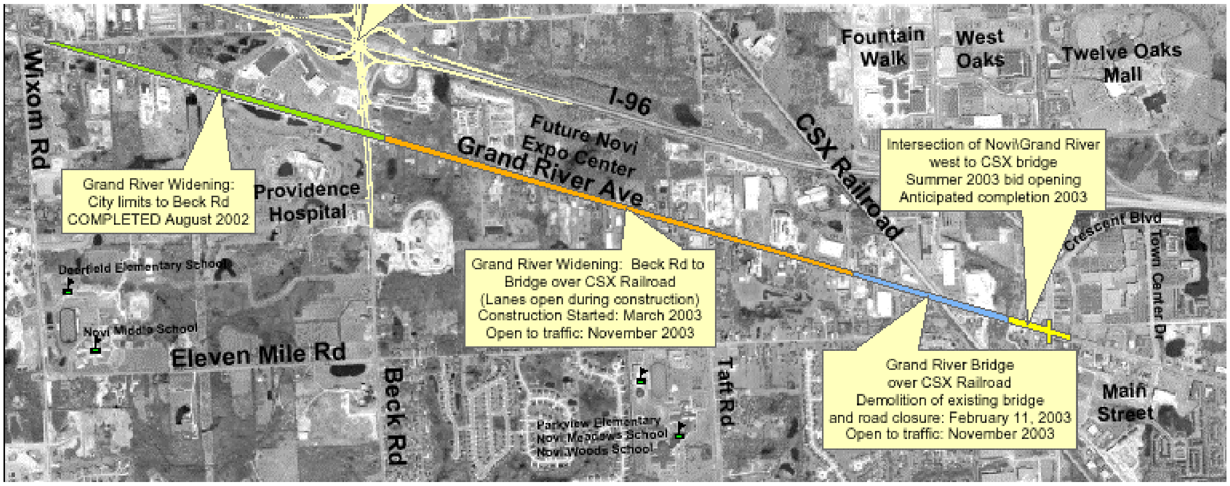

Figure 11, Location Map of Study Location

Field Setup of IQ8T Tag

The IQ8T Tag was placed on to a piece epoxy coated #5 rebar that was 2' long. The tag was fastened to the rebar with four electrical zip strips. The rebar was held up by two tie bar spades at either end. The tie bar spades were pounded into the 21AA gravel base until the top of the tag was 4.5" up from the gravel. The tag was placed at 4.5" since the concrete was 9" and this would place it at mid depth. The tie bar was placed at 2' in from the edge of metal. The tie bar was placed at this location in case the tag needed to be found after the paver passed, it would be easily accessible. Show in Figure 12 is the IQ8T tag set up prior to paving.

Figure 12, IQ8T tag set up

The tag was then buried prior to the first paver with concrete. This is shown in figure 13. This project was paved using a front strike off paver and rear finishing paver.

Figure 13, IQ8T prior to first paver

Tag Locations

A total of 19 IQ8T Tags were placed into the Grand River Road Project for this study. 10 tags were placed in the eastbound direction and 9 were placed in the westbound direction. Shown in figures 14 and 15 are the eastbound and westbound tag locations.

Date	Time	Stencil #	Tag #	Station
7/3/2003	11:25 AM	1	505	88+50
7/3/2003	2:29 PM	2	506	81+50
7/7/2003	9:00 AM	3	507	76+00
7/7/2003	10:00 AM	4	508	73+50
7/7/2003	2:10 PM	5	509	60+50
7/8/2003	9:20 AM	6	510	49+50
7/8/2003	12:45 PM	7	511	39+00
7/9/2003	9:45 AM	8	513	24+50
7/9/2003	12:15 PM	9	514	14+50
7/10/2003	10:10 AM	10	515	74+00 Taft

Figure 14, Eastbound tag locations

Date	Time	Stencil #	Tag #	Station
9/18/2003	2:40 PM	1	519	13+50
9/19/2003	9:50 AM	2	520	20+50
9/19/2003	12:50 PM	3	521	28+50
9/23/2003	9:00 AM	4	522	37+50
9/23/2003	12:40 PM	5	523	44+00
9/23/2003	3:35 PM	6	524	51+25
9/24/2003	1:50 PM	7	525	62+00
9/25/2003	10:40 PM	8	526	76+50
9/25/2003	3:50 PM	9	527	87+00

Figure 15, Westbound tag locations

On each location that a tag was placed the pavement was stenciled with the number shown in the table. Two to three tags were typically placed per day.

Temperature Curves

Shown in figures 16 and 17 are the 28 day temperature curves for the eastbound tag locations.

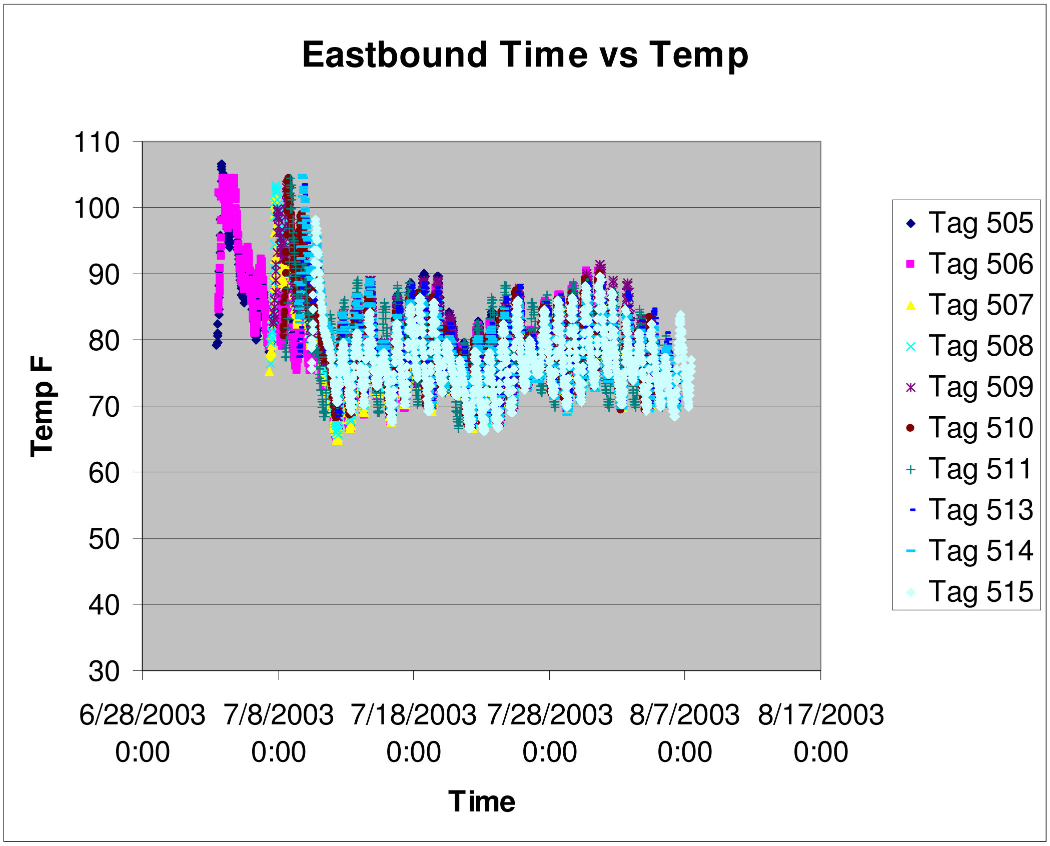

Figure 16, 28 Day Temperature Curves for Eastbound Tags

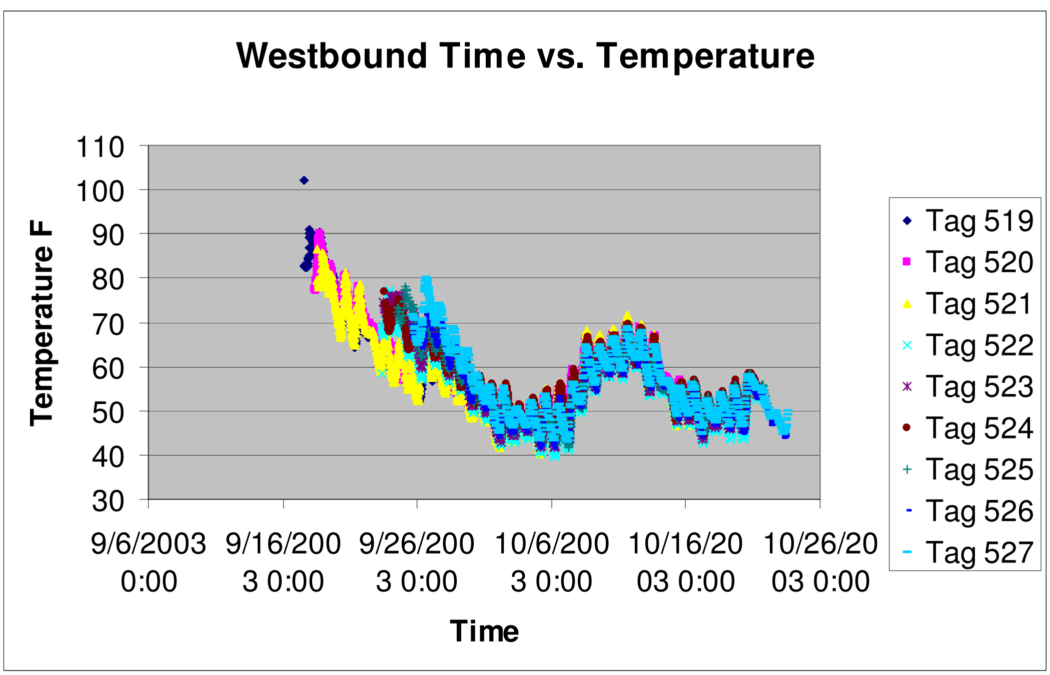

Figure 17, 28 Day Temperature Curves for Westbound Tags

Analysis and Findings

The regular concrete series testing on this project was done by JCK and Associates who also happened to have an office with a test lab on the project. JCK conducted concrete tests through out the day and made anywhere from 2 sets to 6 sets of compressive cylinders depending on how much concrete was placed. The testing was conducted at the batch plant which was located on the west end of the project. The cylinders were field cured at the batch plant. The number of field cured and lab cured days to reach the 28 days varied by the cylinder sets. None of the cylinders for the project were field cured more than 5 days. The impact of field vs. lab curing was not studied on this project, but its impact can not be put aside.

Maturity readings were taken on an as needed basis throughout the project. The maturity readings were used as a tool in helping to decide when to break the compressive strength cylinders. The maturity readings could be taken as often as needed during the day to monitor the strength gain. The result of the compressive strength cylinders, not the maturity was used to decide when traffic could be placed on to the concrete pavement.

In figure 18, are the results for the eastbound tags. The figure shows the tag number, date, age of concrete at cylinder break and maturity reading, variation percentage, and days and method of cylinder cure. The cylinder average column is the average of all the cylinders made on that specific day and broken at the age specified by the age column. The variation is the percentage difference between the maturity results and the cylinder average. A negative variation is when the maturity is higher than the cylinder average and vice versa. The cylinder cure column is the number of days the cylinder was field cured and lab cured until the point at which it was broken.

Tag	Date	Age (days)	Maturity (psi)	Cylinder Average (psi)	Variation	Cylinder Cure
505	7/3/2003	3.76	3114	3342	7.31%	4F,0L
505		6.99	4455	4444	-0.25%	4F,3L
505		28.14	6615	5906	-10.72%	4F, 24 L
506	7/3/2003	3.64	3098	3342	7.86%	4F,0L
506		6.86	4424	4444	0.44%	4F,3L
506		28.01	6615	5906	-10.72%	4F,24L
507	7/7/2003	1.89	2150	1945	-9.53%	2F,0L
507		2.89	2622	2737	4.39%	2F,1L
507		28.06	6615	5988	-9.47%	2F,26L
508	7/7/2003	1.87	2196	1945	-11.43%	2F,0L
508		2.84	2671	2737	2.47%	2F,1L
508		28.02	6615	5988	-9.47%	2F, 26L
509	7/7/2003	1.68	2122	1945	-8.34%	2F,0L
509		2.68	2584	2737	5.92%	2F, 1L
509		27.85	6615	5988	-9.47%	2F, 26L
510	7/8/2003	2.07	2297	2033	-11.47%	2F,0L
510		2.88	2649	2711	2.34%	1F,2L
510		28.05	6615	5637	-14.78%	1F,27L
511	7/8/2003	1.91	2193	2033	-7.27	2F,0L
511		2.72	2567	2711	5.61%	1F,2L
511		27.90	6615	5637	-14.78%	1F,27L
513	7/9/2003	1.87	2116	2085	-1.47%	2F,0L
513		5.09	3469	3404	-1.89%	1F,4L
513		6.96	4174	4244	1.68%	1F,6L
513		28.04	6615	5799	-12.33%	1F,27L
514	7/9/2003	1.79	2117	2085	-1.51%	2F,0L
514		5.00	3501	3403	-2.78%	1F,4L
514		6.85	4203	4244	0.98%	1F,6L
514		27.95	6615	5799	-12.33%	1F,27L
515	7/10/03	3.98	2910	2422	-16.75%	2F,2L
515		5.00	3349	2298	-31.38%	2F,3L
515		27.99	5935	5372	-9.48%	2F,26L
				Avg. Mix#1 Other than 28 day	4.75%	Std Dev. 3.68%
				Avg. Mix#1 28 day	11.56%	Std Dev. 2.26%

Notes: Shown are all tags for Mix #1 except tag 515 which was Mix #2
Average Variation found using absolute value

Figure 18, Eastbound Tag Results

Also shown in the table is an average variation for the tags that were used on Mix#1. The average variation for cylinders broken other than 28 days was 4.75%. The average variation for cylinders broken at 28 days was found to be 11.56%. These averages were calculated by using the absolute value of the variation. An interesting observation from the data in table 1 is that the 28 day maturity result is always higher than the cylinder average. Additionally, of the remaining 22 data points other than 28 days, only 12 of these data points are cases were the maturity is higher than the cylinder average. The data also shows that the method of curing cylinders can impact the results. If one looks at the cylinder breaks prior to 28 days, the first cylinder is typically field cured with no lab cure, the second cylinder and third cylinder is lab cured between 1 and 6 days until it its broken. The variation of the second and third cylinder is typically closer to 0 than that first cylinder which is only field cured.

Shown in Figure 19 are the results for the westbound roadway. The cylinder results are again the average of the cylinders for that day. The cylinder cure is the number of days field cured and lab cured until it is broken. The average variation for cylinders broken other than 28 days was 10.68%. The average variation for cylinder broken at 28 days was found to be 12.87%. These averages were calculated by using the absolute value of the variation. From the data one can see that the variation is always a negative percentage meaning that for every data point shown below that the maturity is predicting a strength higher than the cylinders. One will also notice that anytime there are 2 cylinders broken prior to the 28 day break that the second cylinder has variation closer to zero. The second cylinder has one day to six days of lab cure.

Tag	Date	Age (days)	Maturity (psi)	Cylinder Average (psi)	Variation	Cylinder Cure
519	9/17/2003	4.81	3200	2886	-9.83%	5F,0L
519		27.83	6615	5312	-19.51%	5F,23L
520	9/18/2003	3.98	2875	2175	-24.35%	4F,0L
520		4.98	3238	2923	-9.72%	4F,1L
520		28.02	6615	5498	-16.89%	4F,24L
521	9/18/2003	3.87	2752	2175	-20.97%	4F,0L
521		4.89	3110	2923	-6.00%	4F,1L
521		28.01	6615	5498	-16.98%	4F,24L
522	9/23/2003	6.04	3260	2652	-18.65%	3F,3L
522		9.04	3910	3872	-0.96%	3F,6L
522		28.06	6615	5920	-10.51%	3F,25L
523	9/23/2003	5.94	3300	2652	-19.64%	3F, 3L
523		8.96	3990	3872	-2.94%	3F,6L
523		27.94	6615	5920	-10.51%	3F, 25L
524	9/23/2003	5.75	3192	2652	-16.92%	3F, 3L
524		8.75	3912	3872	-1.01%	3F,6L
524		27.77	6615	5920	-10.51%	3F,25L
525	9/24/2003	4.85	2894	2652	-8.36%	5F,0L
525		7.87	3653	3439	-5.86	5F,3L
525		27.87	6615	5720	-13.54%	5F,23L
526	9/25/2003	3.96	2551	2440	-4.36%	4F,0L
526		27.98	6615	6113	-7.58%	4F,24L
527	9/25/2003	3.75	2554	2280	-10.71%	4F,0L
527		27.95	6615	5959	-9.92%	4F,24L
				Avg. Mix#1 Other than 28 day	10.68%	Std Dev. 7.71%
				Avg. Mix#1 28 day	12.87%	Std Dev. 4.04%

Figure 19, Westbound Tag Results

One of the first observations made from the table above is the impact of the curing of the cylinders. The amount of heat generated by the 24' or 36' wide slab at the time of paving will be substantial greater than that of the concrete cylinder. The cylinders above were field cured for a couple of days and then taken to a laboratory for curing at a uniform temperature until the cylinder break was to take place. The conditions that the maturity tag is experiencing in the concrete slab are much different than the cylinder in the lab. The slab is being affected by the sun, wind, rain, and all of the elements. Therefore, it is most important in future studies and the application of maturity that the cylinders be cured in the field for the entire period that data is being obtained from the maturity tag. One potential problem with leaving the cylinders in the field for 28 days is being able to find a safe place to leave them without getting damaged. The optimum place for the cylinders is as close to the tag the cylinders are being compared to. By changing the way the cylinders were cured during this study, it would have changed the final results and the variation percentages that were found.

During this study two curves were made. The paving of the eastbound roadway took place in early July and the westbound roadway in late September. By looking at figure 15 and 16 one can see the difference in temperatures that were present in the slab in the first 28 days. The slab of the eastbound roadway was in the mid 80's F during the day with lows above 60°F. On the other hand, westbound roadway was in the mid 50's F with lows around 40° F. With over two months between the paving of the two sides of the roadway it would be recommended future work to make new a curve prior to the paving of the second side paving. Additionally, the curve could be made in weather that is closer to what it is going to be applied in. Again, by making this change the results of this study would have been impacted.

A very important part of maturity testing is the curve. The curve was made with a specific type of concrete and materials. The tag is placed into concrete which may or may not be the exactly the same as the concrete that made the curve. The important part is that some variation will always be present due to potential changes in the concrete plant, materials, and placement methods. The maturity curve is intended for the mix design that it was made for and if the mix design is changed, then a new curve should be made.

To monitor the performance of the curve it has been suggested that the curve be validated during placement. In order to do this a tag would be placed into one of the cylinders during making. When a cylinder break is to take place a TTF reading would be made. This point would then be plotted on the original maturity curve. The American Concrete Paving Association suggests that for concrete cylinders the cylinder break and the curve should be within 500 psi. If the two are more than 500 psi apart then a new curve should be created. Due to time, cost, and manpower the curve on this project was not validated. On future projects the curve should be validated.

Overall, the data from this study is promising. The intent of this study was to look at the early age open to traffic concrete strength and not the 28 day strength. The data shows that the cylinders were 4-11% from the maturity results for the breaks performed in the first 8 days. By making some of the modifications stated above, the cylinder and maturity results could have been brought closer together.

Importance of Maturity to Reconstruction of Grand River Avenue

The CMMS was an important tool used in the reconstruction of Grand River Avenue. The maturity system provided instant real time concrete strength results. Without attaching a box to any wires coming out from the concrete slab, Tony Angelo Cement Construction Company could monitor the strength gain of the concrete through a wireless transmission as often as they would like to. During critical times readings were often taking a couple of hours apart to monitor the strength in effort to move traffic on to the concrete at some of the businesses. The maturity systems on this project helped to eliminate the dependence on the person perform the concrete series testing. All too often the concrete results on some projects can't be obtained because the cylinders are still in the field, the testing person can not be found or the cylinders are in the lab but have not been broken, or the cylinders were destroyed in the field and they are no longer any good. By using the concrete maturity monitoring system the results were right there in the hand held device.

The CMMS also helped the project from the stand point of scheduling. Operations that needed to be conducted following concrete paving and curing could be scheduled with confidence from the maturity readings. For example, pouring of driveways, curb and gutter, joint sealing, could all be scheduled as early as possible by knowing how the concrete is gaining strength.

The impact to local businesses was reduced by using the CMMS. By knowing the concrete strength with the click of a button, traffic at businesses which were going through gaps in the mainline concrete pavement could be switched on the pavement and the gaps filled as soon as the proper strength was obtained.

Cost of CMMS Testing

The benefits of CMMS far out weigh the cost. The cost for a starter set which includes the Compaq iPAQ, expansion pack with PCMCIA Card, antenna, software, and 20 IQ8T tags cost is approximately $4,400.00. The IQ8T tags sell between $44.00 and $68.00 depending on how many are purchased. WAKE, Inc. has reviewed other more industrial grade handheld devices that utilize the Microsoft Pocket PC operating system with an open slot for the RFID, PCMCIA card. These types of handheld devices represent one of the fast growing areas for the manufactures, thus broader choices are now available depending on the customers need. Furthermore, the IRD Software is available in Microsoft PC format that will allow the system to operate on a laptop PC that has a PCMCIA card placed in it.

After obtaining the CMMS additional cost are incurred during the making of the maturity curves. To make the curves an individual will be needed that can perform concrete series testing and make the necessary cylinders. Furthermore, the cylinders will need to be broken and this will cost around $20.00 each.

Once the initial investment is made into the equipment and the necessary curves established, the only other cost that will be incurred is the person in the field performing the readings or making any cylinders to verify the curves. This of course would depend on the project by which maturity is being used on.

In the not to far distant future concrete maturity testing will be a part of our everyday concrete paving and construction projects. Maturity testing may one day replace all of the cylinders that are made and reduce the number of people making these cylinders.

Other Applications for the CMMS

The CMMS could be used to monitor freeze and thaw cycles in concrete, cold or hot weather effects on mix designs using certain materials, strength gain in concrete bridges to name a few.

Shown in Figure 20, is a graph of concrete temperature vs. time for a tag that was placed into some concrete paving done on September 16, 2003. The graph shows tag readings from December 16, 2003 to January 25, 2004. From the graph one can see that the concrete has gone through at least 3 freeze thaw cycles during this time period. The wireless concrete maturity system could be used to monitor if a particular concrete was frozen during its early age strength gain. Additionally, how well is the cold weather protection on the concrete working? Did the hot water, hot sand, or blankets keep the concrete from freezing? Did the concrete get to hot?

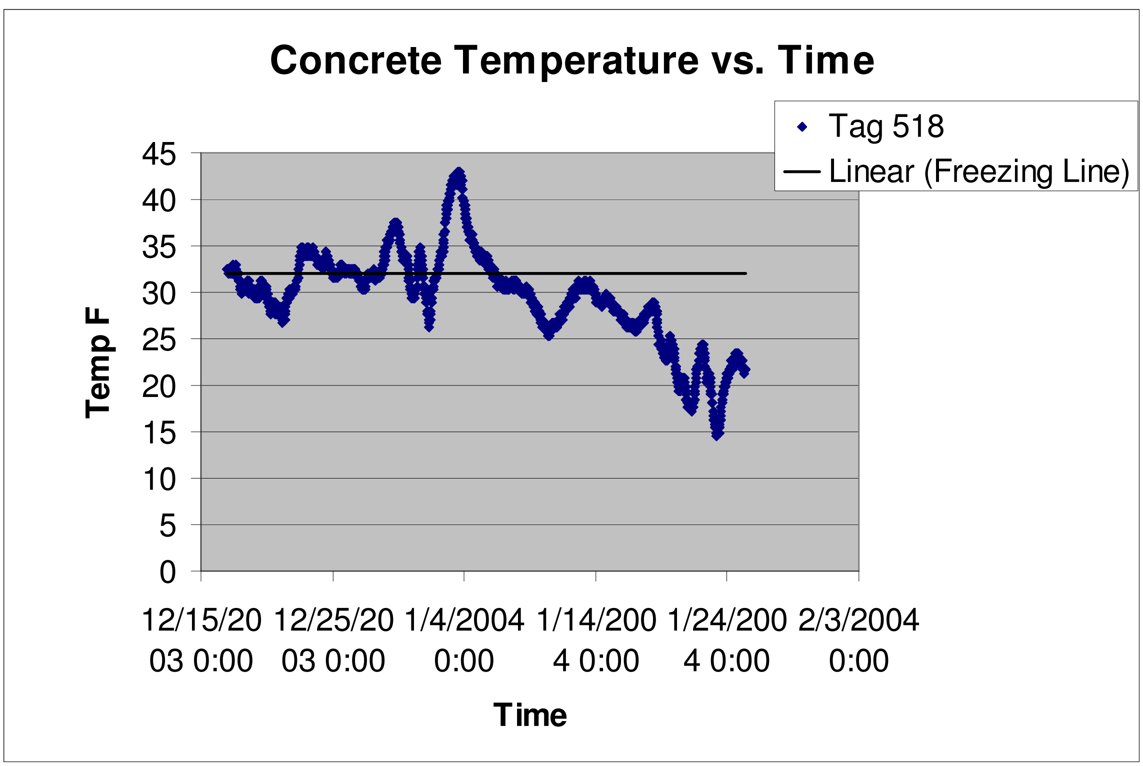

Figure 20, Concrete Temperature vs. Time, Freeze Thaw

The CMMS could also be used in studying the effects of cold or hot weather on mix designs containing certain materials. For example, it is specified by MDOT that concrete placed in Michigan after October 15 should not contain any Ground Granulated Blast Furnace Slag (GGBFS). The GGBFS will slow down strength gain in cold weather. However, if one where to place concrete with GGBFS and monitor the strength gain a temperature dependent specification could be developed instead of date specific. The maturity system would provide data to the exact impact that the cold weather is having on the strength gain. From this data temperature specific ranges with the amount of GGBFS could be specified. Shown in figure 21 is two strength vs. time curves of concrete both containing 35% GGBFS in different weather conditions. The curve labeled #526 Grand River was placed on September 25, 2003. Over the 4.25 day period for this curve the average concrete temperature was 65°F and the average air temperature was 57°F. The curve labeled tag #529 Subdivision was placed into a subdivision on November 15, 2003. Over the 4 day period for this curve the average concrete temperature was 57°F while the average air temperature was 45°F. The mix designs for both projects were the same except the subdivision used 2NS Hot sand. Even though the two concretes were placed during different weather conditions, the 2NS Hot has kept the subdivision concrete with in 450 psi of the Grand River concrete at 4 days. An expanded study using this type of comparison would be a great tool to be used in creating a temperature specific specification for GGBFS use in Michigan.

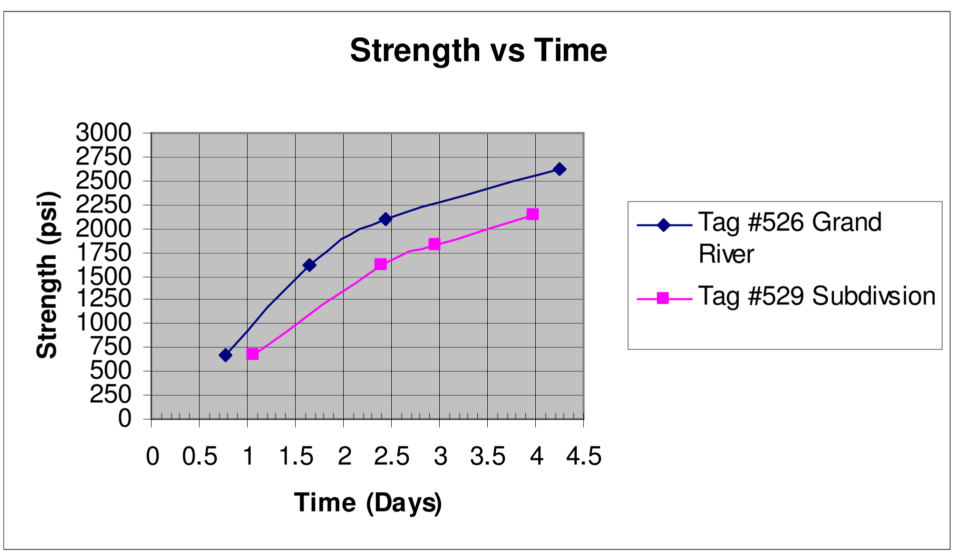

Figure 21, Strength vs. Time

The CMMS could also be used on bridges and concrete patches throughout Michigan. The real time strength gain data would provide the same types of benefits as those found on Grand River.

Conclusion/Recommendations:

- The CMMS provided good concrete strength gain results for the Grand River Avenue Reconstruction project. The results were found to be within 4-11% of the concrete cylinders that were made for the project for prior to 28 days.

- By making some adjustments to the method of the curing of the concrete cylinders and the verification of the curve the difference in strength between the cylinders and the maturity readings could have been reduced during this study.

- The CMMS was easy to use, performed terrific and became a valuable tool to the reconstruction of Grand River Avenue. 100% of the tags placed on this project worked.

- The CMMS far out weighed the initial capital investment that must be made.

- A specification allowing the use of Concrete Maturity on MDOT projects is the next step.