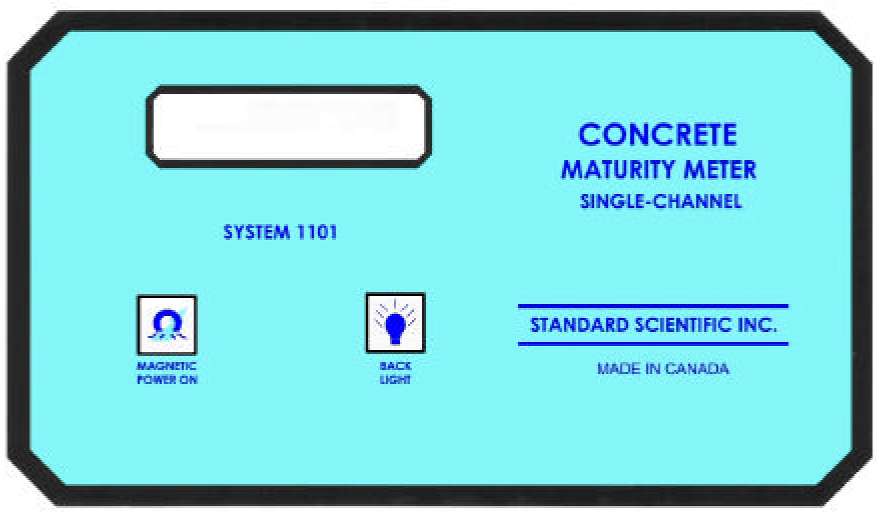
SYSTEM 1101R

CONCRETE MATURITY METER
RECHARGEABLE MODEL

OPERATIONS MANUAL

JANUARY 2003



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Model 1101 Concrete Maturity Meter

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IMPORTANT NOTICE

INTRODUCTION

The Model 1101 Maturity Meter provides accurate, predicable concrete strength determination by monitoring the concrete temperature via a disposable thermocouple wire. Some of the benefits of using this meter on the construction site include:

- Form and Shoring Removal Time Predication
- Loading and Post-Tensioning Time Prediction
- Control of Winter Heating and Insulation Requirements
- Accelerated Construction Scheduling

Years of experience using data logging electronics in construction environments are behind the Model 1101 Maturity Meter Design. It is housed in a water-tight, impact resistant enclosure and includes one 12V rechargeable lead acid battery.

Thermocouple temperature sensing is utilized to enable long or short cable runs and to allow flexibility and ease of placement of the temperature sensor. Low cost, type “T” thermocouple wire is used. Status indicators include transducers open-circuit and over/under range monitors. Connections are made via a quick-connect thermocouple jack.

Temperature and cumulative degree-hour values are displayed simultaneously on a ½” high liquid crystal display. The unit power/reset circuit is magnetically operated.

Please familiarize yourself with this manual before using the meter. There are some helpful hints that could save you time and money.

METER OPERATION

INTRODUCTION

The Model 1101 Concrete Maturity Meter is a very simple instrument to operate. The measured concrete temperature is displayed continuously along with the maturity "temperature-time" factor. Read through the following operational instructions to become familiar with the meter and then use the appendix as required for more details.

If you want to know more about applying the maturity concept to concrete strength estimation, please refer to ASTM C1074-93, "Estimating Concrete Strength by the Maturity Method".

Turning The Meter On and Off

The meter power switch is actuated by holding a magnet horizontally against the top of the enclosure at the icon marked "Magnetic Power ON". A magnet is included with the Maturity Meter but virtually any magnet will work. The switch has a toggle operation wherein the magnet must be removed and returned to the icon in order to turn the power off. The maturity value is reset to zero by turning the meter off and on.

Alarm Conditions

There are alarm indicators that can be seen on the LCD display.

They are:

"Open-Circuit"—The warning "Please Plug in Sensor Probe" will trigger if there is a break in the thermocouple cable. Check the cable and plug wiring.

The too hot alarm trigger is set at a default temperature of 71 deg. C (160 F). The alarm code reads "Too Hot".

Similarly, the low temperature alarm reads "Too Cold". This alarm is set at a default of –11 deg C (12 F).

"Low Battery" – This alarm triggers when battery power drops to 7.5V. The test will continue but the liquid crystal will display "TEST CONTINUES RECHARGE SOON." The battery warning will continue on the display until the battery voltage drops to 6.5V. At this level the test will still continue but the liquid crystal will cease to display.

Thermocouples

Thermocouple temperature sensors are used because they are economical and rugged. They are ideally suited to maturity meter applications as different length cables, deep sensor placement and complex for work are easily accommodated.

"T" type thermocouples made of copper – constantan are used. They are available in ± 0.5 or ±1 degree C accuracies, in a wide range of wire diameter and insulation types, and are inexpensive. Thermocouple wire can be purchased from most wire companies and is available (along with standard connectors) from distributors of this meter.

Cable Preparation

To prepare a thermocouple temperature transducer you will need a length of "T" type wire of 24 gauge or larger size and a standard "T" type thermocouple plug. These plugs are included with the meter and they are available through Maturity Meter distributors or any of a number of different manufacturers. For long cable runs use heavier gauge wire and if the situation warrants, consider the used of armoured cable.

The thermocouple wire has a polarity to it, the copper being the (+) side and the constantan (silver in colour) being the (-) side. Disassemble the plug, separate the wire pair one inch (1") and strip half an inch (1/2") off of each lead. Making sure that the polarity is correct, connect the wires to the plug and reassemble.

To form the temperature transducer at the other end of the wire, strip the wire end as above but this time twist the two leads together (use a pair of pliers to insure that the connection is solid). The point where the wire leads are twisted together forms the temperature transducer. To make as permanent a connection as possible it is recommended that the wires be soldered as well. To prevent damage or corrosion, plastic dipping using a material such as "PLASTI-DIP" is also recommended.

Thermocouple cables may be prepared at the office so that site installation is accomplished in as efficient a manner as possible. Cables may be reused by cutting off old cables at the concrete interface and following the same procedure as for a new cable.

Meter and Thermocouple Placement

When using the meter on the construction site you should keep the following points in mind:

- The most common cause of Maturity Meter failure is from accidental damage. Secure the meter away from high traffic areas and materials that might be moved when you are not around.

- Long cable runs can be a problem if routed through high traffic areas or around materials that might be moved. Try to keep the cable lengths as short as possible.

- Concrete is very dense and can rip thermocouple wire when being poured. Vibrators are often used which can cause the reinforcing bars and mesh to vibrate violently. To reduce the possibility of transducer failure, carefully place the wires around the reinforcing bars. Make sure the wiring is done before the forms are completed. For critical areas, wire more than one thermocouple so that you have a backup if a transducer "Open Circuit" occurs.

To avoid over estimating the concrete strength, try to place the temperature sensor in a cooler section of the concrete placement. See ASTM standard C1074-93 for more information.

Battery Information

Charging port at bottom right hand corner. Charger must be plugged into a 120V / 60 Hz service. Full recharge requires 12 to 14 hours. Units left unused require a full charge once a year at least to retain recharging capability.

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Two Important Notes:

(1) Static voltage can damage electronic equipment so do not touch the internal printed circuit boards.

(2) Meter operation greatly above or below 20 deg C temperature will reduce the battery capacity. Battery capacity during long-term storage decreases to 80% - in 8 months at 20 deg C, and 80% in 2 months at 40 deg C. therefore, storage at lower temperatures is preferable.

Wire Care and Attention

The Maturity Meter is housed in a polycarbonate enclosure that is an extremely strong material. It resists scratching, maintains its flexibility over a wide range of temperatures and is impervious to most solvent. With occasional washing the enclosure will stay looking good for long time.

Cement is hydroscopic in nature and contact with the enclosure will eventually cause the lid machine screws to become devoid of lubrication. A drop of oil will make the screws easier to loosen.

The thermocouple jacks should be kept free of any dirt or concrete dust. Electrical contact cleaner is not recommended but alcohol and a small wire brush could clean out stubborn dirt.

Maturity Concept Theory

In the last few years, there has been a good deal of investigative work done in the area of concrete strength determination through electronic temperature measurement. This work is based on the findings of J.M. Plowman, who first advanced the time-temperature rate of gain of strength in Portland cement concrete in 1947.

There are various methods of relating the concrete time-temperature data to strength, but most methods employ the integrated value of temperature with time.
The “Maturity Value: is given by:

$$M = SUM [t (T + 10)]$$

Where M = Maturity (degree C x hours)
T = Average concrete temperature (degree C)
t = Duration of curing (hours)

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Interpolation of integrated temperature value on pre-determined strength versus time-temperature graphs enables instant strength calculations. Because concrete continues to gain strength down to about -10 degrees C this value is usually used as the integration "datum- temperature" and is the value used by the Model 1101 Meter for the maturity "temperature-time: factor calculation. This maturity factor can be adjusted to reflect any desired "datum temperature" by using the technique described on the following page.

Although different concrete mix designs exhibit similar curing characteristics, each should be tested to determine its exact strength/maturity relationship. This is done by making a number of cylinders, monitoring one or more of the cylinders with a maturity meter and breaking pairs of cylinders at 3, 7, 14, 28… days. It is possible to use the maturity concept to determine future strengths from present values, so it possible uses the maturity concept where pre-determined graphs are not available.

Maturity Values are converted to strength estimates through the use of prediction equations. The subject of converting maturity values to concrete strength estimates is dealt with extensively in the ASTM (American Society of Testing and Materials) Standard C1074-93. Anyone using maturity meters should obtain a copy of this standard either through you local library or directly through ASTM. This standard also provides instructions on how to select maturity function constants (parameters) for different types of concrete and gives clear example calculations.

Logarithmic Prediction Equation

The most common methods of plotting the maturity values are by using a semi-log graph. The graph paper should have 3 complete logarithmic decades spanning 100, 1000, 10,000 and 100,000 degree x hours. The vertical linear scale can be adjusted to suit the maximum strength of the particular concrete mix design being used although many firms use a single standard "maturity graph".

The basic logarithmic function that describes the plot is given as follows:

$$Q = a + b \times \log(M)$$

Where M = Maturity (degree Celsius x hours)
Q = Compressive Strength (psi or Mpa)
a = Regression Constant
b = Regression Constant

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Two or more test values must be plotted on the semi-log graph (strength/maturity values) and a best-fit straight line is drawn through the points. Regression constants “a” and “b” may then be found from the graph slope and offset. (See next page).

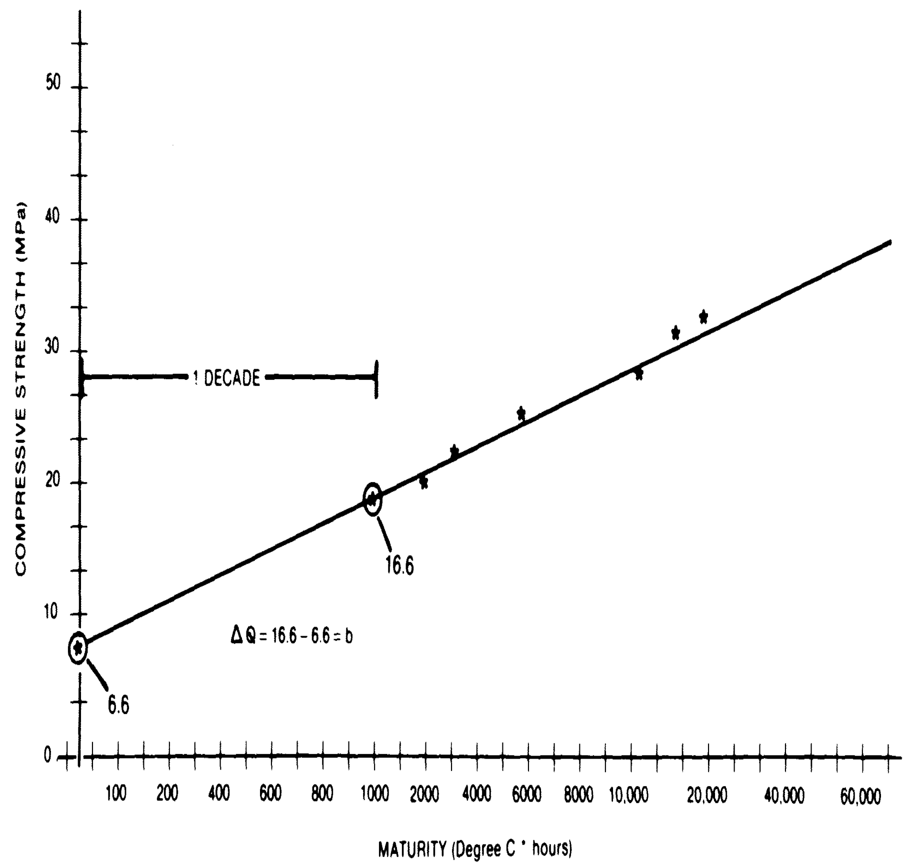
Given the equation above, the regression constant:

$$b = Q\ (@\ M{=}1000) - Q\ (@\ M{=}100)$$

and then the regression constant:

$$a = Q - b \times \log(M)$$

The resulting graph (or predication equation) may then be used to interpolate site concrete strength values from maturity values.



Graph 1. Determining Regression Constants for the Logarithmic Prediction Equation.

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Hyperbolic Predication Equation

Recent studies have suggested that the use of hyperbolic prediction equations may be more accurate then the commonly used logarithmic prediction discussed. The graph paper you should use will have linear scales on both axis. The inverse of the concrete strength is plotted against the inverse of the maturity values so that the hyperbolic curve is transformed into a straight line.

The basic hyperbolic function which describes the plot is given as follows:

$$Q = a \times M/(b + M)$$

Where	M	=	Maturity (degree Celsius x hours)
	Q	=	Compressive Strength (psi or Mpa)
	a	=	Regression Constant
	b	=	Regression Constant

Two or more test values must be plotted on the inverse graph (strength/maturity values) and the best fit straight line is drawn through the points. Regression constants “a” and “b” may then be found from the graph. It can be seen that the regression constant “a” is equivalent to the limiting strength (which is the inverse of the intercept) and that the regression constant “b” is equivalent to “a /A” where “A” is the inverse of the slope of the straight line. See Graph #2.

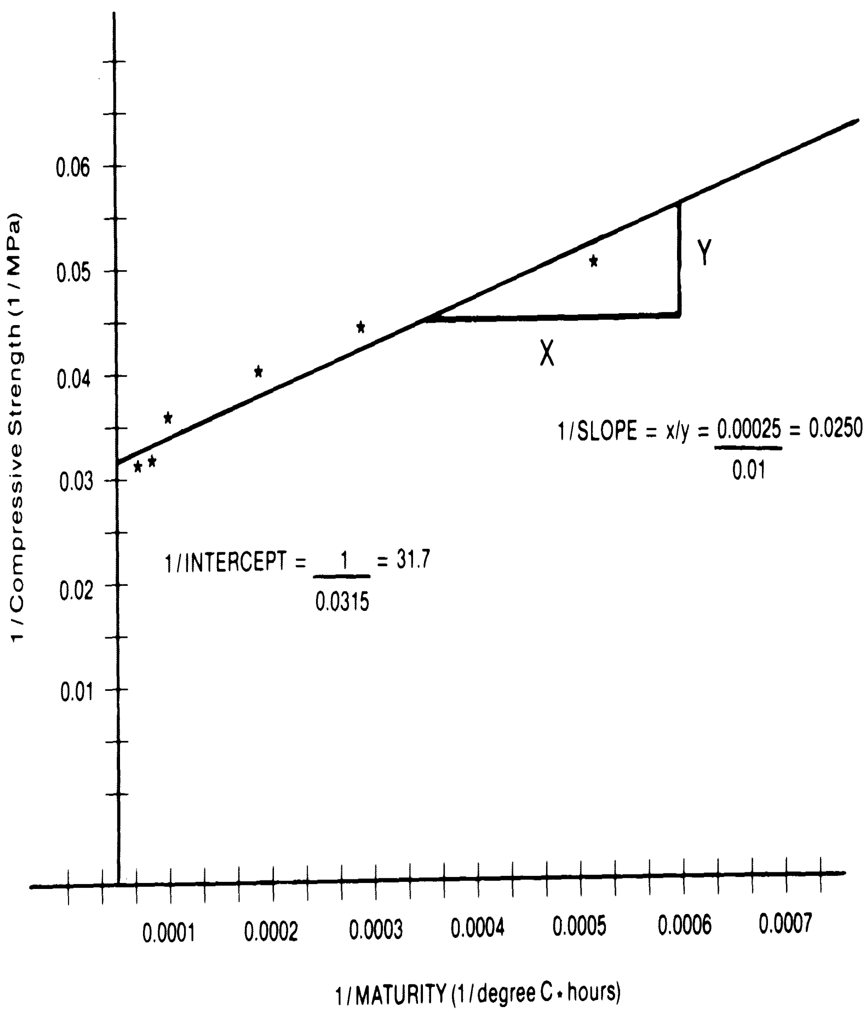
The resulting graph (or predication equation) may then be used to interpolate site concrete strength values from maturity values.

A more accurate form of the hyperbolic prediction equation is given as follows:

$$Q = \frac{(M - Mo)}{A + (M - Mo)/b}$$

Where Mo is the offset maturity introduced to account for the concrete induction period (strength development does not start at zero maturity).

To achieve a straight line curve as in the simpler hyperbolic prediction equation it is necessary to replace the term M with (M – Mo). When low strength-maturity test values are plotted, the offset maturity Mo must be subtracted from the maturity M if the data is to fall on a straight line when the inverse plot is constructed.



Graph 2. Determining Regression Constants for the Hyperbolic (Inverse) Prediction Equation.

Power Prediction Equation

Reference 5 tested three prediction equations for accuracy: the logarithmic equation, the hyperbolic equation, and the powers equation, as follows:

$$M/Q = aM^b$$

In that study it was found that this prediction equation gave the lowest overall error. To simplify determination of the regression constants it would save time to use a curve fitting program on the strength-maturity test results. No manual method for determining the constants will be presented here although the resultant prediction equation can be used to interpolate site concrete strength value from maturity values in the same way as for logarithmic and hyperbolic prediction equations.

Predicting Future Strengths From Present Values

As discussed, the hyperbolic prediction equation can be determined from two or more early strength-maturity values and the resultant equation can then be used to predict later strength values. It was found that for the simpler case of the hyperbolic function that a ±15 percent accuracy could be expected from this technique as long as one of the data points was from a 50 percent or greater strength value.

Use of the second, more complex hyperbolic equation will allow earlier strength-maturity values to be used as long as the offset maturity Mo is properly taken into account.

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Error Analysis

Many of the references listed, give test results for the use of the maturity concept to predict concrete strengths. Errors reported seem to be mostly in the range of 5 to 10 percent. The errors are dependent on the type of mix design, the time-temperature profile of the concrete, the datum temperature used, etc.

Generally speaking, a datum temperature of –10 degrees C will suffice for concrete pours in normal ambient temperature (-10 to +30 degrees C). Modification of the datum temperature to a higher value (as much as +20 degrees C) for accelerated curing conditions is advisable.

The accuracy of maturity meter temperature measurements affects the strength prediction error in the following manner. The lower the concrete temperature, the higher the accumulated error and the earlier the maturity reading, the higher the error. This can easily be seen by observing that (the measurement accuracy {in degrees}) divided by (delta T {the integrated temperature}) gets larger as the temperature drops. Also, as time increases, the prediction equations "compress" the maturity value so that the effect of measurement errors decrease.

As an example of the effect of the temperature measurement accuracy on the prediction error, assume ±1.5 degree measurement accuracy. The strength determination error (due to the meter) after a 50 hour interval is less than 1 percent. Therefore, the error due to the maturity meter can effectively be ignored in most situations.

For situations where the error introduced by the temperature measurement might affect the concrete strength prediction accuracy it is recommended that "special limits of error" type T thermocouple wire be used. This wire has a ±0.5 degree C accuracy versus ±1.0 degree C accuracy for the standard type T thermocouple wire.

Shifting the Datum Temperature

The datum temperature is preset at the factory. Occasionally other datum temperatures may be preferred. The mathematical calculation follows. If you determine that you require a new datum, your meter may be returned to the factory for recalibration, or a new meter ordered with the different datum.

In some situations it might be desirable (for accuracy reasons) to shift the datum temperature in prediction calculations from –10 degrees C to some other value. Maturity readings can be converted to the new datum temperature with the following mathematical manipulation:

First calculate the average temperature for each maturity value recorded.
The basic Maturity equation:

$$M = \Sigma\Delta t(T + 10)$$

Can be re-written as

$$M = d(Ta + 10)$$

Where d = duration of curing (hours)
Ta = verage temperature over duration d (degrees C)

Therefore:

$$Ta = M/d - 10$$

Converting a maturity value to a new datum temperature is then:

$$M = d(Ta + 10 - \{Td + 10\})$$

Comparison with Other Strength Determination Techniques

The other “non-destructive” concrete strength estimates are possible with Windsor Probes and Pullout Tests. Both methods have disadvantages.

The Windsor Probe tests may not be performed at full power when the concrete is young since physical damage and poor data can result. Use of Windsor Probes on young concrete usually results in inaccurate readings. Values obtained will generally be unacceptable for concrete that is less than 60 percent of the limiting strength.

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Pullout tests (and variations there-of) are often impractical due to form work considerations. As well, a sufficient number of pullout units must be initially installed so as to assure that the desired strength is reached before all the pullouts are used. These tests only determine the strength of the outmost edge of the concrete and cannot always be considered accurate for determining inner concrete strengths.

Example Test Procedure and Calculations

To determine a predication equation for a particular concrete mix the following procedure should be followed:

1. Mix enough concrete so that 12 standard size cylinders can be made.

2. Cast the cylinders with a thermocouple wire embedded in the middle of one of the cylinders. Connect the thermocouple wire to a Maturity Meter and note the time of the pour.

3. Place the cylinders under a sheet of plastic and weigh it down. Ambient temperatures between 10 and 25 degrees C will suffice.

4. Break pairs of cylinders at 2, 4, 7, 21 and 28 days noting the maturity value at each break.

5. Construct a table as follows (values included as an example):

Cylinder #	Time (Hours)	Maturity Value (degree X Hrs)	Strength (Mpa)	Comment	Averaged Strength (Mpa)
1	48	1920.	19.6	good	19.9
2	48	1920.	20.2	good	
3	96	3648.	22.4	good	22.7
4	96	3648.	23.0	good	
5	168	5880.	25.1	good	25.3
6	168	5880.	25.4	good	
7	336	11088.	27.5	good	27.5
8	336	11088.	-------	bad break	
9	504	16128.	30.8	good	30.7
10	504	16128.	30.6	good	
11	672	18816.	30.9	good	31.0
12	672	18816.	31.0	good	

Table #1. Example of Strength-Maturity Test Data.

6. For a logarithmic prediction equation, plot the values on a semi-long graph.

7. The logarithmic equation is:
Q = a + B x log(M) so the regression constant b = Q(@M = 1000) – Q(@M = 100) = 16.6-6.6 = 10.0, and then a = Q-b x log(M) = 20.0-10.0 x log(2000) = -13.0

The prediction equation has been determined to be:

$$Q = -13.0 + 10 \times \log(M)$$

8. For a hyperbolic predication equation, first calculate the inverse of the strength-maturity values.

Strength (Mpa)	**Maturity (deg X hrs)**	**1/Strength (1/Mpa)**	**1/Maturity (1 deg X hrs)**
19..9	1920	0.0503	0.000521
22.7	3648	0.0441	0.000274
25.3	5880	0.0395	0.000170
27.5	11088	0.0364	0.0000902
30.7	16128	0.0326	0.0000620
31.0	18816	0.0323	0.0000531

Table 2. Example of Inverse Strength-Maturity Values.

9. Plot these values on a full inverse graph.

10. The hyperbolic equation is: Q = a x M/(b + M). The regression constant a = 31.7 (the limiting strength which is the inverse of the intercept). The regression constant b = a/A = 31.7 / 0.0250 = 1286. (Where 0.0250 is the inverse of the slope of the straight line).

11. The hyperbolic predication equation is given by:

$$Q = 31.7 \text{ x } M/(1268 + M)$$

SPECIFICATIONS

Temperature Measurement

Thermocouple Wire	Type T
Sensor Measurement Range	-10 deg C to +70 deg C
Accuracy	± 1 deg C

Battery

Type	12V – 2.2 amp/hr Rechargeable Lead Acid

Mechanical

Dimensions	20cm (7.8”) X 12cm (4.7”) X 7cm (2.9”H)
Case Material	Polycarbonate
Weight	1.6 KG (3.5 LBS)
Thermocouple Connector	OST-T-F (plug)

Environmental

Operating Temperature	-10 deg C to +60deg C

Meter Care

Please Keep The Meter Out of Direct Sunlight to avoid the LCD being damaged as they will eventually become **BLACK** in appearance and will be unreadable.

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Term of Test

At the default setting of one minute sampling intervals, the meter will accumulate up to 32677 deg C / Hours after which the word "ENDED" will be displayed. Further readings will stop.

Enclosure	Splash Resistant Impact Resistant

Maturity Value Calculations

Maximum Maturity Values Displayed:

Temperature-Time Factor	32677 deg C / Hours

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