TEMPLUG
USER INFORMATION
GUIDE

REVISION 4.1

2017

TESTING ENGINEERS, INC.

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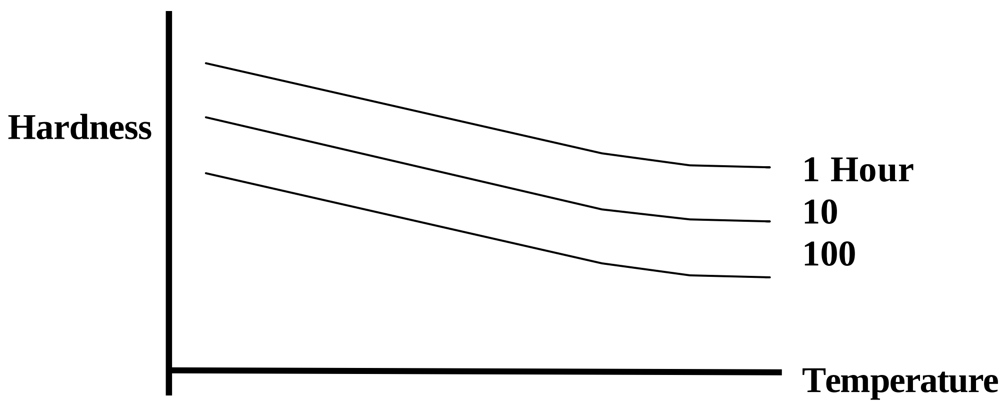
INTRODUCTION

TEMPLUG is a temperature sensitive steel set-screw and is used for determining the maximum temperature in locations that are difficult to instrument using conventional "thermocouple type" techniques (moving engine parts, turbine blades, and bearings are a good examples of typical applications). The part being tested **does not** need to be made of steel; nickel alloys, aluminum, composites, ceramics can be tested with this technique[1]. By drilling and tapping, a **TEMPLUG** can be installed directly into the location at which temperature needs to be measured. **No other instrumentation necessary!**

TEMPLUGS were developed in the early 1970's in a joint effort by **Testing Engineers Inc. (TEI)** & "Shell Research". They function on the principle of thermal tempering (thermal softening) of a hardened steel. Master calibration curves of the type shown below were developed by "Shell"[2] for special heat treated alloy steels and are the basis for determining the maximum temperature. Beware of imitations that have not been proven, **TEMPLUGS** are the original temperature indicating device. TEI is a nationally recognized ISO compliant laboratory that maintains the highest quality control standards, and the only **TEMPLUG** laboratory in North America.



From the above curves, the maximum temperature is determined based on the time of exposure (known from experimental conditions) and the measured hardness.

1 Thermal expansion needs to be considered to prevent damage to the test part.
2 New curves for a new more controlled alloy have been prepared by the current manufacturer, Vernolab, France.

TEMPLUG CHARACTERISTICS

a) Temperature Limits

TEMPLUG are made from two alloy steels which are sensitive in the following temperature ranges:

Type of Steel	Temperature Range, F (˚C)	
	MIN.	MAX
No. 2 Steel	165 (74)	1200 (649)
No. 3 Steel	1020 (550)	1565 (852)

A more specific discussion covers the minimum and maximum temperature ranges for **TEMPLUG** under "Temperature and Time Limits" (pages 6 & 7).

b) Design

TEMPLUG set-screws are available in two sizes, dimensions specified in metric units.

1. M3 x 0.5 (3mm diameter, 0.5 mm pitch)
2. M1.6 x 0.35 (1.6 mm diameter, 0.35 mm pitch)

Besides their size, there are two other important differences between the two **TEMPLUG** designs.

1. The M3 type **TEMPLUG** has a socket on the non-measuring end facilitating installation and removal (Figure 1). The tool used for this purpose is a "Torx" Wrench, size T-6. The smaller M1.6 **TEMPLUG** is installed by twisting the break-off handle (Figure 2) and can be removed from the test part using penetrating oils, strong magnets, and skilled technicians. In most cases the user has to return the test object or a portion thereof for temperature evaluation.

2. The entire length of the M1.6 **TEMPLUG** is hardened. The socket section of the M3 **TEMPLUG** is tempered (softened) to prevent cracking during installation.

In order to distinguish between the No. 2 steel and the No. 3 steel, the No. 3 steel **TEMPLUG** of both designs (M3 and M1.6) has been slightly modified as shown in Figures 1 and 2.

TEMPLUG DESIGN CHARACTERISTICS

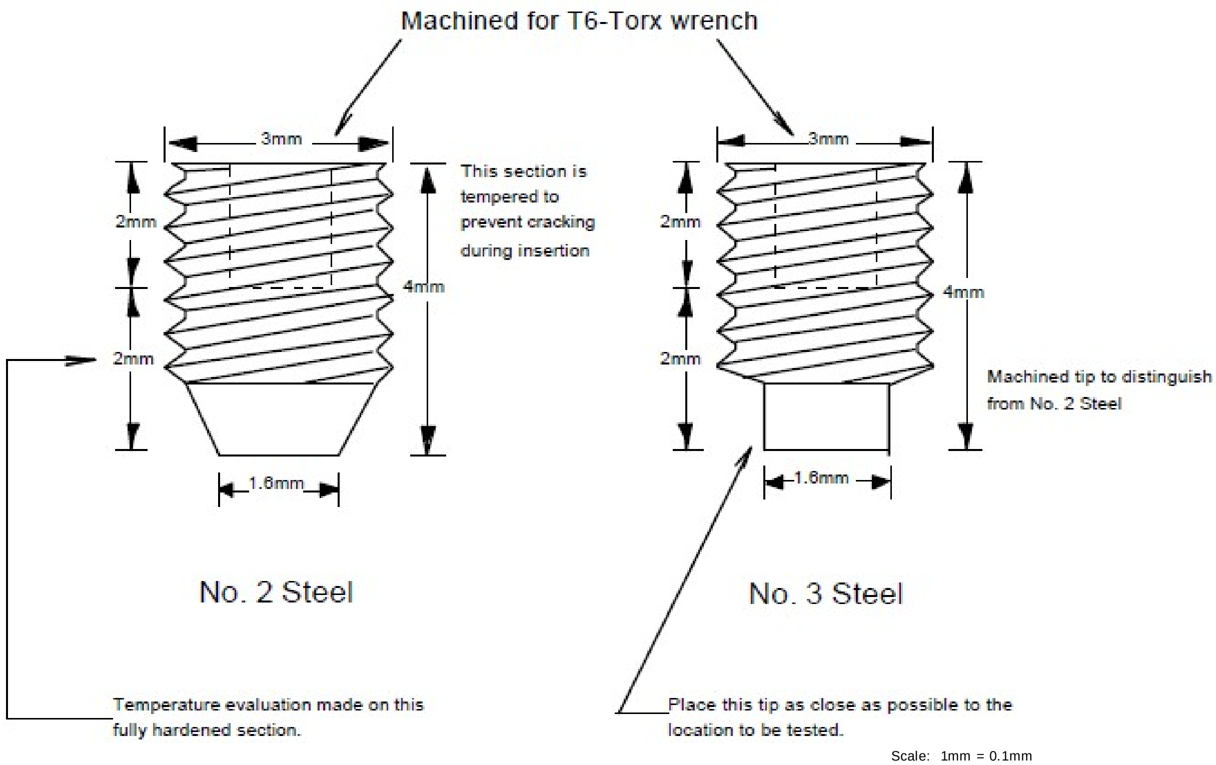
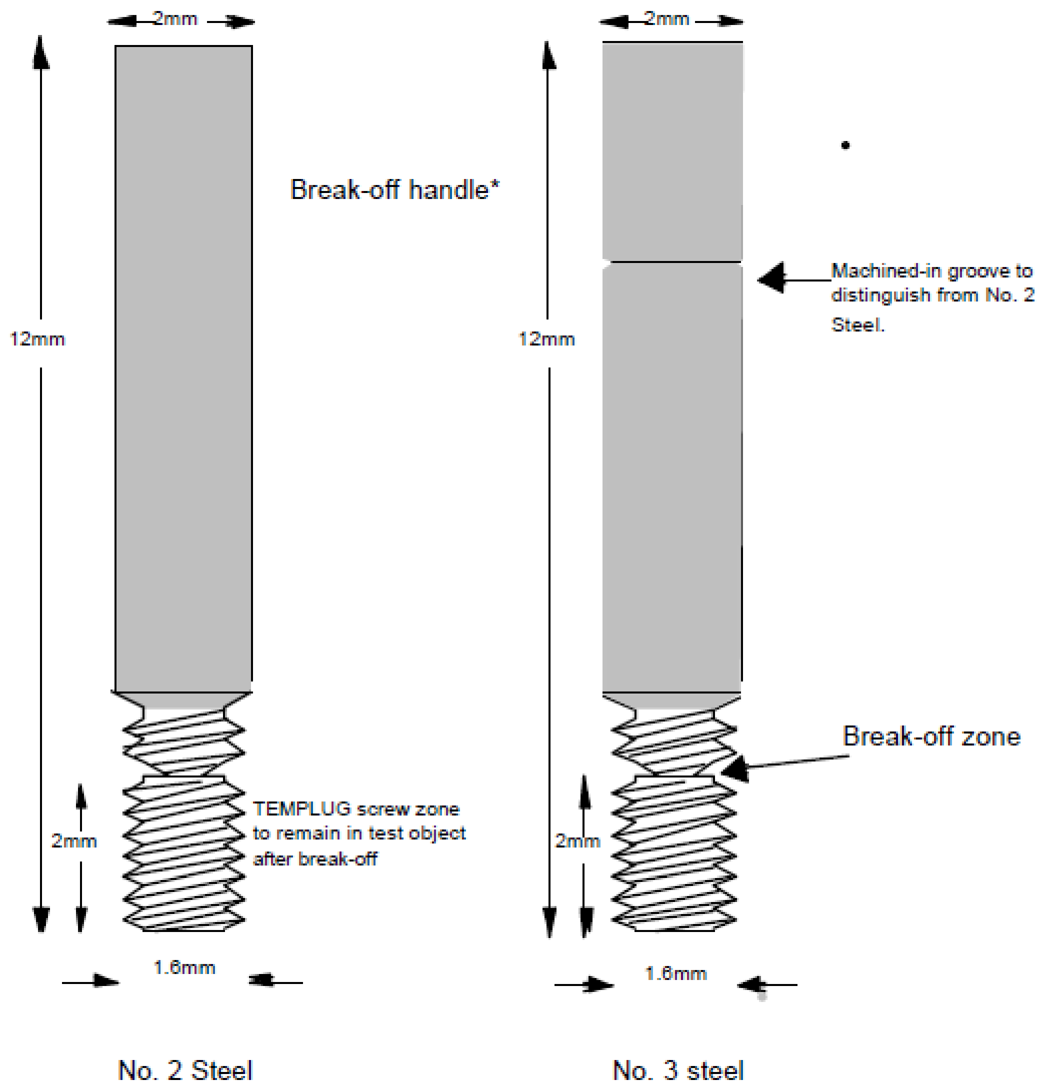


FIGURE 1
Standard M3 x 0.5 TEMPLUG

TEMPLUG DESIGN CHARACTERISTICS



* The handle may be used for test exposure and evaluation since handle and plug are fully hardened.

FIGURE 2

Small M1.6 x 0.35 Break-off TEMPLUG

TECHNICAL INFORMATION

In order to obtain accurate and reliable data with **TEMPLUG**, the following considerations have to be kept in mind:

a) Temperature/Time Cycles

The ideal temperature/time cycle for determining maximum temperature would be where the **TEMPLUG** is heated rapidly to a uniform maximum temperature, maintained at this temperature followed by rapid cooling. This cycle simulates conditions that are used for generating the master calibration curves and consequently, should minimize error. The ideal cycle has been shown in Figure 3. **TEMPLUG** are sensitive more to temperature than to time. Based on this, two acceptable temperature/time cycles are shown in Figures 4 and 5. The critical aspect about these cycles is that at least 25% of the total time should be at the maximum temperature. The greater this percentage, the more accurate the maximum temperature measurement.

b) Temperature and Time Limits

The minimum and maximum temperatures that can be determined with the No. 2 **TEMPLUG** for a variety of exposure times are given below. The least exposure time is 1 hour and the maximum exposure time is 100 hours.

EXPOSURE TIME	**MIN. TEMP. F (C)**	**MAX. TEMP. F (C)**
1 Hour	261 (127)	1200 (649)
4 Hours	219 (104)	1220 (660)
24 Hours	176 (80)	1220 (660)
100 Hours	165 (74)	1146 (619)

Exposure times in between the ones listed above can also be used without introducing any error in temperature determination.

b) Temperature and Time Limits (Cont'd)

Similar information for the No. 3 **TEMPLUG** is presented below. The least exposure time for the No. 3 **TEMPLUG** is 1 hour and the maximum exposure time is 100 hours.

EXPOSURE TIME	**MIN. TEMP. F (C)**	**MAX. TEMP. F (C)**
1 Hour	1022 (550)	1565 (852)
4 Hours	1022 (550)	1565 (852)
16 Hours	1022 (550)	1550 (843)
100 Hours	1022 (550)	1565 (852)

Exposure times in between the ones listed above can also be used without introducing any error in temperature determination.

c) Alterations to TEMPLUG

A user may desire to alter the **TEMPLUG** by reducing the length or diameter to accommodate certain test configurations. This is allowable without compromise of results under the proper conditions. The minimum length of an altered **TEMPLUG** should be no less than 1mm with a minimum diameter of no less than 1.3 mm. Be extremely careful to ensure that any work that is performed on the **TEMPLUG** prior to the test exposure will introduce errors if sufficient heat is generated to cause the temperature to rise above the subsequent test temperature. The problem can be avoided by careful grinding under water. **TEI** Metallurgists should be consulted if grinding or other such alterations are required. Alterations to the socket end of the M3 style **TEMPLUG** are much safer, of course, since in that case the work location would be away from the critical flat tip used for the peak temperature determinations. Alterations to plugs is done at the discretion of the user and may reduce the accuracy of reported temperatures. TEI does not guarantee temperature accuracy of altered plugs.

d) Corrosion

TEMPLUG has the same corrosion resistance as carbon or alloy steels of the non-stainless varieties. Since the important flat tip is usually buried, providing protection from the atmosphere, corrosion is seldom a problem for **TEMPLUG**. However, if the conditions of time, temperature and atmosphere are deemed problematic, **TEMPLUG** can be protected by encapsulating in a stainless steel holder, or by plating.

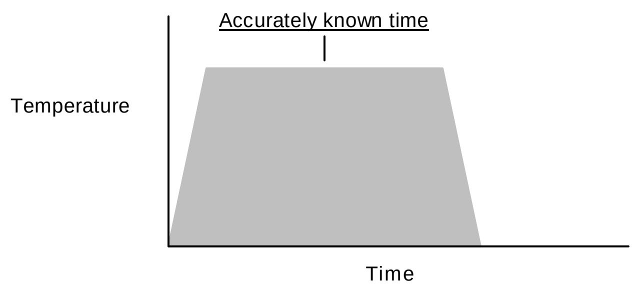


FIGURE 3 - Ideal Temperature/Time Cycle

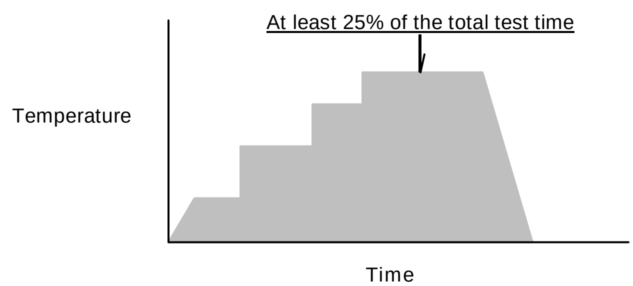


FIGURE 4 - Acceptable Temperature/Time Cycle

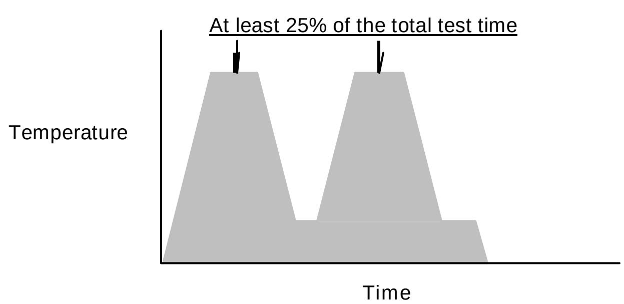


FIGURE 5 - Acceptable Temperature/Time Cycle

ACCURACY OF RESULTS

TEI takes a great deal of pride in performing tests accurately and professionally. **TEMPLUGS** eliminate the need for costly instrumentation necessary for more accurate methods of temperature measurements. Most locations tested with **TEMPLUGS** are critical highly stressed areas of moving parts that cannot easily be measured with other measuring devices. Typically, our customers are more concerned with relative temperatures between locations on the test part, and between consecutive tests, than the absolute exact temperature.

This method of determining peak temperatures is limited by at least four major variables; the material itself, the tempering process, the test procedures followed while exposing it to elevated temperatures and the method of determining final hardness. Careful manufacturing procedures are followed to ensure that inaccuracies relating to the first two items are minimized. **TEI** also performs random quality control testing of incoming **TEMPLUGS** from the manufacturer in accordance with our Quality Control Manual using an automated Leco microhardness tester, shown in Figure 6. We have confidence that our customers take as much pride and care in following rigorous and meticulous testing practice. The method of measuring hardness is therefore the critical factor influencing the results of the temperature measurements. We estimate that if a properly conducted test as described by Figure 3, the maximum temperature can be determined accurately to within 3%. For the acceptable temperature/time cycles shown in Figures 4 and 5, the maximum temperature can be determined accurately to within 4.5%. The higher the percentage of time spent at maximum temperature conditions, the greater the accuracy.

FIGURE 6 - Leco AMH43 Automated Microhardness Tester.

Other factors that affect accuracy are inaccurately reported exposure times, and temperature spikes or "overshoots".

These factors are discussed below:

a) Inaccurately Reported Exposure Time

The following table shows the error that would be introduced in the maximum temperature measurement based on inaccurately measuring the peak exposure time:

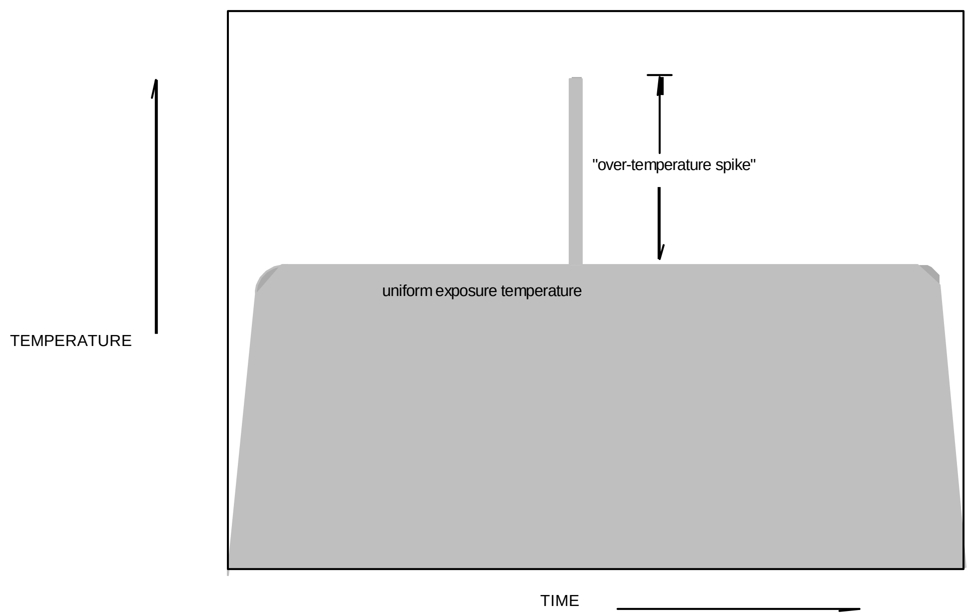
EFFECT OF ERROR IN COUNTING TIME

Cycle Time (Recorded)	**Peak Temperature (Assumed)**	**Time Error (Assumed)**	**Temperature Error (Max.) (From Data)**
1 Hour	572 F (300 C)	5 Minutes	2 F (1 C)
2 Hours	572 F (300 C)	5 Minutes	< 2 F (1 C)

The table shows that after 1 hour, exactness in reported exposure time is not critical. The relationships shown above also apply to maximum temperatures other than the 572 F used in the example.

b) Temperature "Spikes or Overshoots"

Research has shown that a temperature "spike" of the type shown in Figure 7 has to be between 85 F and 140 F before it will produce a measurable change in the maximum temperature. A "spike" in excess of the above magnitude can produce a measurable effect on the maximum temperature in as little as 0.1% of the total exposure time.



<u>FIGURE 7</u> - Exposure cycle with "over-temperature" spike

CONDUCTING A TEST

a) Installation

Drill and tap the holes required at the desired **TEMPLUG** locations, using ISO 3 x 0.5 tap for M3 plugs and ISO 1.6 x 0.35 for M1.6 plugs. The holes have to be bottomed with a bottoming tap. The flat test end of the **TEMPLUG** should be installed such that the **TEMPLUG** is securely bottomed in the tapped hole (torque 0.4 Nm). Each hole should be drilled sufficiently deep to avoid protrusion of the socket or break-off end. Since the flat tip of the **TEMPLUG** is the area tested for peak temperature, it is suggested that the hole bottom be located close to the desired measurement area if possible. A small error may be introduced if the **TEMPLUG** location cannot accommodate this recommendation.

Secure the M3 **TEMPLUG** in the hole tightly with a Torx (T-6) head wrench or tool. The usual right angle wrench may be used or a pin vise may be preferred for ease of manipulation. If additional security is desired to prevent the **TEMPLUG** from unscrewing during the test, an organic cementing agent may be used, such as "Loctite"*, however, the **TEMPLUG** may be very difficult to remove, or may require sectioning by TEI. In order to facilitate removal, use silicone fluid to coat the **TEMPLUG** and take care not to deform the plug during installation. If heat is used in removal of the **TEMPLUG**, the user must be certain that the resultant temperature does not exceed that of the test. The introduction of additional heat during plug removal should be avoided.

Another method to assure **TEMPLUG** will stay in place is to lightly peen one side of the **TEMPLUG** hole after the **TEMPLUG** has been installed. When testing is complete, the smeared metal can easily be removed and **TEMPLUG** backed out. This method is used primarily for aluminum alloys.

When installing the subsize, M1.6 **TEMPLUG**, extreme caution must be exercised so as not to inflict a bending moment on the handle. The handle and the threaded portion are fully hardened and consequently very brittle.

<u>Record the test time for **TEMPLUG** exposure</u>, starting to count time when it is believed that the test article has reached peak operating conditions. Report to **TEI** any other information of possible importance, such as short temperature "spikes" or high or low temperature excursions during a relatively constant cycle. It is preferable that a detailed report of the temperature/time cycle be provided with the **TEMPLUG**.

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* **Manufactured by Loctite Corporation.**

b) Removal

Remove the M3 **TEMPLUG** by unscrewing and placing them in their respective board locations. Care should be taken to indicate exposure time (Time spent under conditions that generated maximum temperature) in the space provided on the board.

For M1.6 **TEMPLUG** and M3 **TEMPLUG** that resist removal, the article with the **TEMPLUG** in it should be mailed to our laboratory. In the event that sectioning is necessary, precautions should be taken not to heat the articles such that the **TEMPLUG** measurements would be affected.

A **TEI** Consultant is available for advice on installation or the selection of test locations. If necessary, **TEMPLUG** installation can also be performed by **TEI**. Some of the many components which have been successfully tested using **TEMPLUG** are as follows: pistons, piston rings, valves, valve guides, valve seats, cylinder heads, fuel injector nozzles, turbine wheels, engine timing gears, turbine blades, bearing races, wrist pin bearings and ceramic components.

c) Ordering

TEMPLUGS can be ordered directly over the telephone from **TEI** at (510) 835-3142. Overnight delivery service is available. Tooling kits for installing **TEMPLUGS** are available and can be ordered along with the **TEMPLUG**.

TEMPLUGS are shipped in lots of 10 on a board as shown in Figure 7. Each board is serialized and the **TEMPLUGS** are numbered so the individual **TEMPLUG** can be related to their position in the actual test. In addition, space is provided under such **TEMPLUG** for reporting the time spent at maximum temperature conditions.

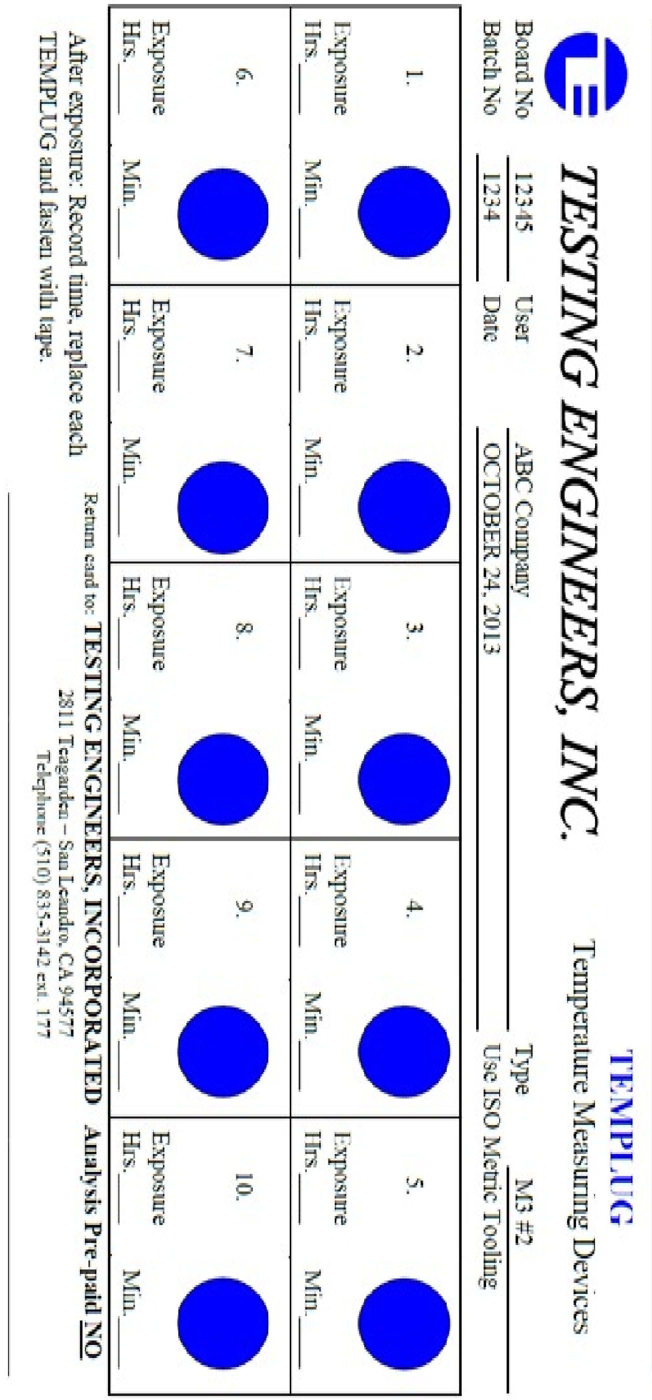
CONDUCTING A TEST (Cont'd)

d) Analysis & Reporting

After receiving used **TEMPLUG**, the analysis is expedited and results conveyed via email in a timely manner. This is followed by a written report. Typical time involved for analysis is given below:

NO OF TEMPLUGS	TIME FOR ANALYSIS
< 20	7-10 Business Days
21 - 50	7-10 Business Days
51 - 100	7-10 Business Days
> 101	9+ Business Days

If required, the analysis time may be expedited even further. Please call us at (510) 835-3412 ext. 177 to inquire about rush fees.


TESTING ENGINEERS, INC.

TEMPLUG
Temperature Measuring Devices

Board No 12345 User ABC Company Type M3 #2
Batch No 1234 Date OCTOBER 24, 2013 Use ISO Metric Tooling

1. Exposure Hrs.___ Min.___	2. Exposure Hrs.___ Min.___	3. Exposure Hrs.___ Min.___	4. Exposure Hrs.___ Min.___	5. Exposure Hrs.___ Min.___
6. Exposure Hrs.___ Min.___	7. Exposure Hrs.___ Min.___	8. Exposure Hrs.___ Min.___	9. Exposure Hrs.___ Min.___	10. Exposure Hrs.___ Min.___

After exposure: Record time, replace each TEMPLUG and fasten with tape.

Return card to: TESTING ENGINEERS, INCORPORATED Analysis Pre-paid NO
2811 Teagarden – San Leandro, CA 94577
Telephone (510) 835-3142 ext. 177

Figure 8 - **TEMPLUG** Shipping Board