# TEMPLUG
# USER INFORMATION
# GUIDE

**REVISION 3.0**

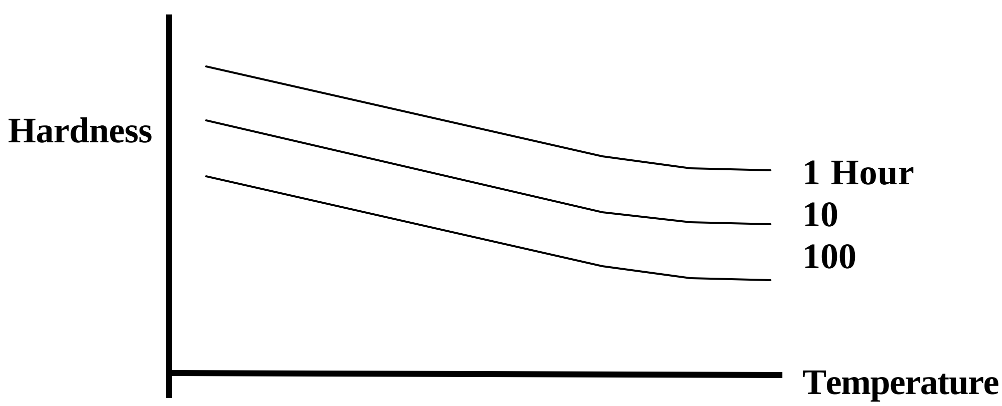
**APRIL 2004**

# TABLE OF CONTENTS

# 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 **TEI** & "Shell Research". They function on the relatively simple 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.




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

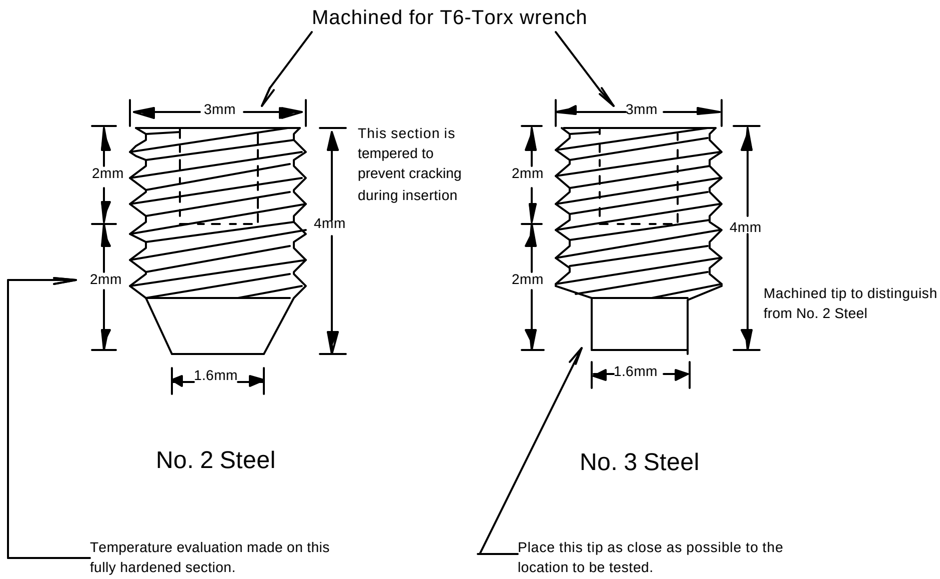
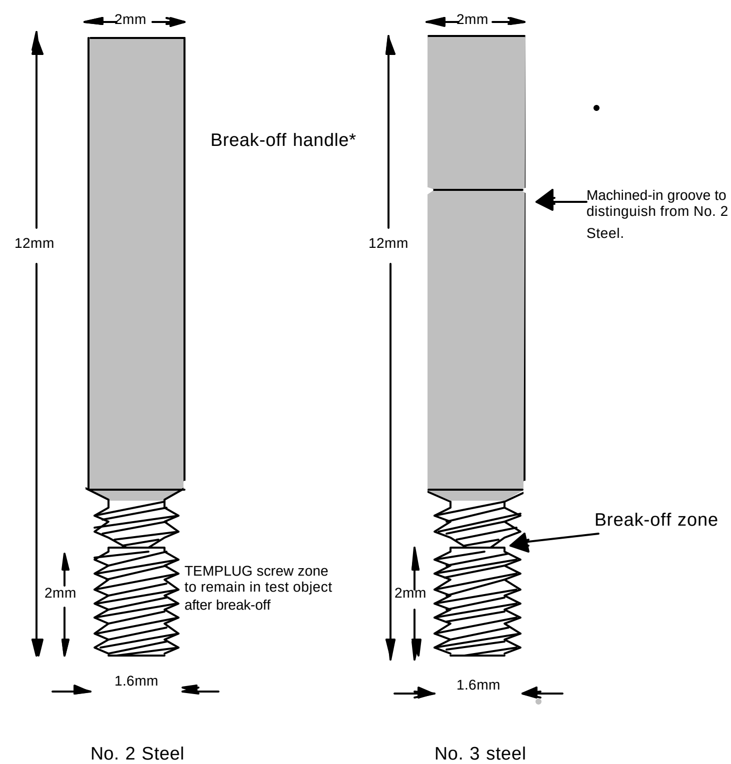



**FIGURE 1**

Standard M3 x 0.5 TEMPLUG

Scale: 1mm = 0.1mm

## 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

Scale: 1mm = 0.1mm

# 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.

## 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 problematical, **TEMPLUG** can be protected by encapsulating in a stainless steel holder, or by plating.

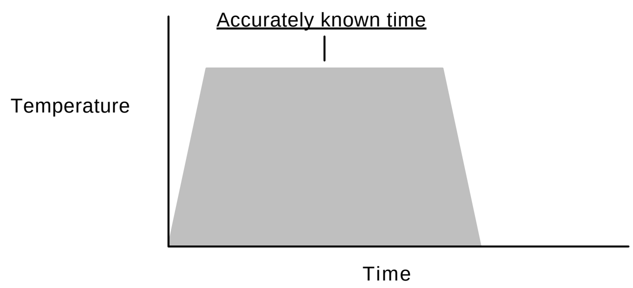



**FIGURE 3** - Ideal Temperature/Time Cycle

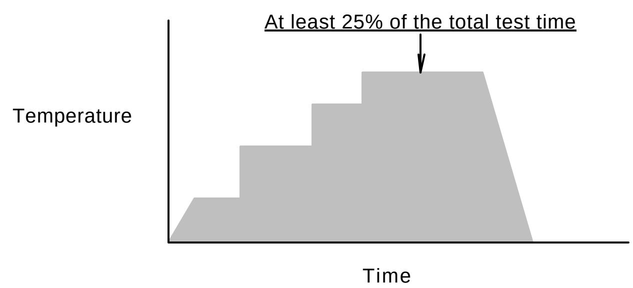



**FIGURE 4** - Acceptable Temperature/Time Cycle

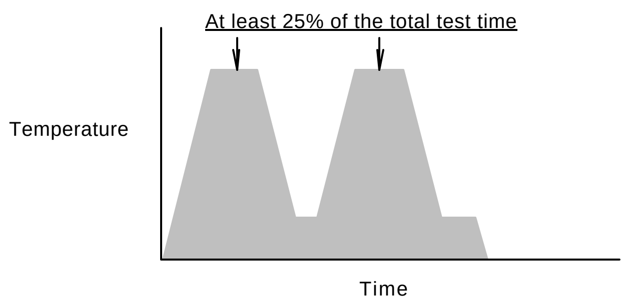



**FIGURE 5** - Acceptable Temperature/Time Cycle

## 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 being 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. 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.

Other factors that can affect accuracy are inaccurately reported exposure time 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 6 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.

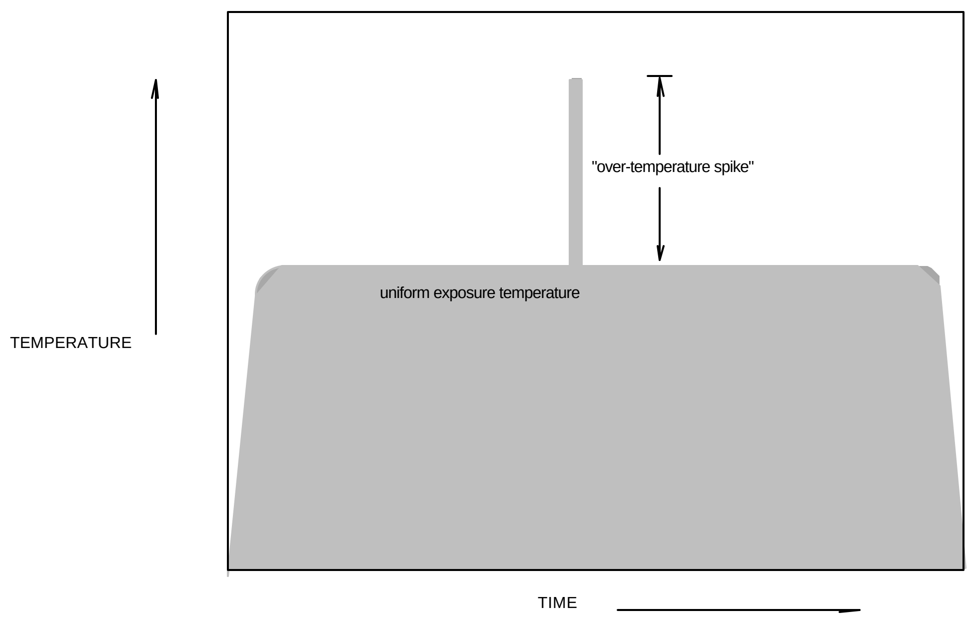



**FIGURE 6** - Exposure cycle with "over-temperature" spike

## CONDUCTING A TEST

a) Installation

Drill and tap the holes required at the desired **TEMPLUG** locations. 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. 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. 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.

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. Refer to Appendix A for additional tips on installation & removal techniques.

<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**.

## CONDUCTING A TEST (Cont'd)

---

* **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**.

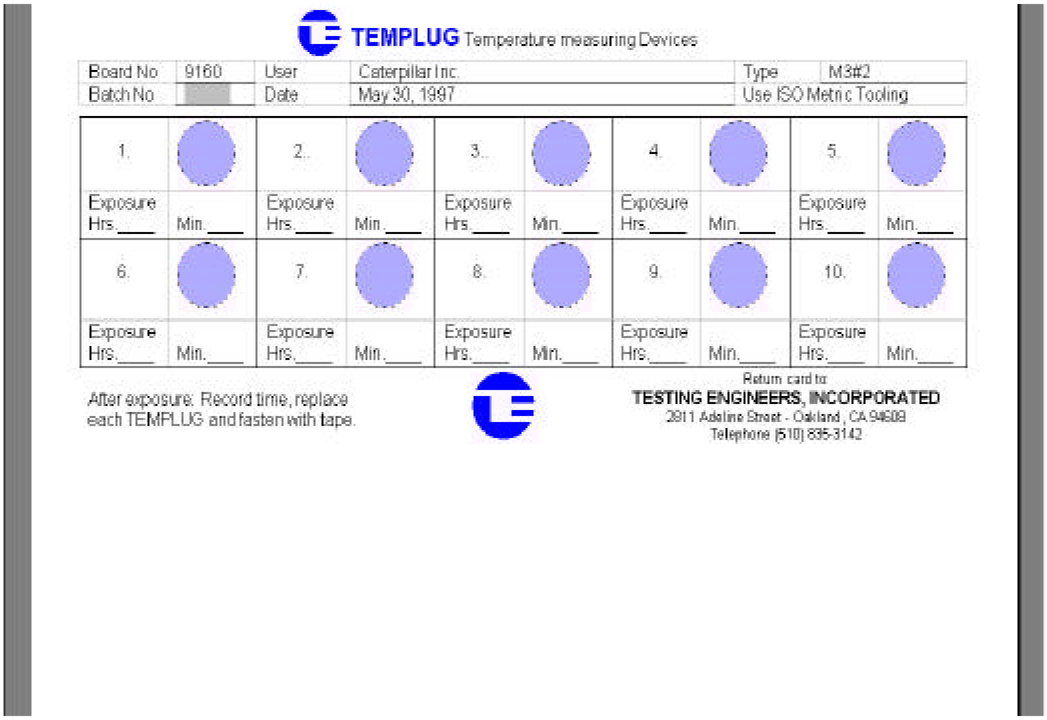
**TEMPLUGS** are shipped in lots of 10 on a board as shown in Figure 7. Each board is serialized and the **TEMPLUGS** are numbered so the individual **TEMPLUG** can be related to their position in the actual test. In addition, space is provided under such **TEMPLUG** for reporting the time spent at maximum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

d) Analysis & Reporting

After receiving used **TEMPLUG**, the analysis is expedited and results conveyed over the telephone or via fax immediately. This is followed by a written report. Typical time involved for analysis is given below:

| NO OF TEMPLUGS | TIME FOR ANALYSIS |
|---|---|
| < 20 | 1 Day |
| 21 - 50 | 2 Days |
| 51 - 100 | 3 Days |
| > 101 | 5 Days |

If requested, the analysis time may be expedited even further.



**TEMPLUG** Temperature measuring Devices

| | | | | | |
|---|---|---|---|---|---|
| Board No | 9160 | User | Caterpillar Inc. | Type | M3#2 |
| Batch No | | Date | May 30, 1997 | Use ISO Metric Tooling | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | | 2. | | 3. | | 4. | | 5. | |
| Exposure<br>Hrs.____ | Min.____ | Exposure<br>Hrs.____ | Min.____ | Exposure<br>Hrs.____ | Min.____ | Exposure<br>Hrs.____ | Min.____ | Exposure<br>Hrs.____ | Min.____ |
| 6. | | 7. | | 8. | | 9. | | 10. | |
| Exposure<br>Hrs.____ | Min.____ | Exposure<br>Hrs.____ | Min.____ | Exposure<br>Hrs.____ | Min.____ | Exposure<br>Hrs.____ | Min.____ | Exposure<br>Hrs.____ | Min.____ |

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

Return card to:
TESTING ENGINEERS, INCORPORATED
2911 Adeline Street - Oakland, CA 94608
Telephone (510) 835-3142

Figure 7
**TEMPLUG** Shipping Board

# Appendix A
# 1996 - TEMPLUG ROUND TABLE NOTES[3]

## Size M1.6 Templugs without sacrificing

The techniques described in the following notes and comments came about for the following reasons:

1. The hardware into which the Templugs would be installed, is quite expensive. Given that the materials from which the hardware was manufactured (such as Inconel 718; VIM-VAR M50, a bearing steel; MAR-M-247; etc.) was either very hard ($R_C$ 60+) or very tough (does not readily form a chip, hence tapping can be quite a lot of fun) and usually both, machining multiple test pieces would be very expensive.

2. It was anticipated that there would be multiple tests. Being able to use the same test article, in successive tests. To measure the affects that changes to surrounding or related pieces of hardware was important. As testing progressed the emphasis changed from problem identification to optimization of the final solution. Machining multiple test articles for a series of tests simply would have been prohibitively expensive, time consuming, and would not have supported the test schedule for problem resolution (at the peak of the current test series we were turning a 78 to 105 Templug test every 2-3 days).

3. The actual test could be tailored, that is, conducted in a manner that would lend itself to easy repeatability and would optimize the test results from the Templugs. For this series of tests a peak exposure time of 4 hours was used since:

    a. A calibration curve for both No. 2 and No. 3 materials was available and hence interpolation for test results would be eliminated which would speed processing of the Templugs.

    b. This test duration ensured that 80% of the exposure time was at the test condition and any secondary effects would be minimized. In general, it has been my observation that the longer the test is run, the test results tend to be more uniform. Our 4 hour time has come about from a lot of prior testing and data analysis. Chances are, different hardware and machines will require different test times.

For our tests, we use the M1.6 size Templugs since they fit our hardware. In the latest test series, M3.0 Templugs could not have been installed in 6 of the 12 positions we instrumented on the disk. Of the six position where M3.0 Templugs could have been installed three (3) positions would have to have been changed and the other three (3) positions were not critical (and in general were being used as sort of "reference" positions anyhow). In short, without the M1.6 size Templugs we could not have run the tests and would have had to resort to other more costly and time consuming techniques.

---

[3] See Credits at the end of this section.

**Installation & Removal**

To accomplish the objective of being able to remove the M1.6 Templugs, we used a flat bottomed hole with a shim stock (or foil) patch over the end, spot welded in place. The hole size we used was 0.0634/0.0638 inches diameter X 0.080/0.085 inches deep, flat bottomed with a 0.005/0.010 inch corner radius. The covering (retaining) patch is usually 0.002/0.003 inches thick X 0.156/0.188 inches in diameter.

We machine our holes using a single lip, flat bottomed cutter. The cutter itself is fabricated from solid carbide blank; usually 0.188 or 0.250 inches in diameter. At our facility, we custom grind the cutters on a "Deckel" cutter grinder. Depending on the material to be machined slight variations to the cutter diameter and rake angle are required. Experience from the latest test shows that we instrumented (machined) two Inconel 718 disks (previously precipitation hardened and aged) with 78 holes each and used a total of 5 cutters to do both parts. To put twenty (20) MAR-M-247 (5 blades, 4 holes) required two (2) cutters. The holes are not pre-drilled, but rather are bored to the correct size. We have successfully used cobalt (particularly M42 cobalt tool steel) alloys as well.

In fairness to this discussion, we have also used M1.6 x 0.35 taps from both cobalt and carbide to tap holes and we were successful, however, our time per hole was on the order of 2 hours/hole (verses approximately 20 to 30 minutes for a bored hole).

I have also used EDM (Electron Discharge Machining) with unsuccessful results. The surface texture of an EDM'd hole (which is quite rough), I believe is the main problem. The roughness of the hole’s wall allows the crests of the Templug thread to catch and makes it virtually impossible to dislodge. Should there be any oxidation of the Templug, you can quit wasting time and forget it.

One thing we do, that seems to enhance our success at removal is; we **do not "break"** the handle off the Templug after it is installed in the hole. Rather, using two needle-nosed sets of pliers we "break" the Templug off the handle and then install the plug in the hole. The number of Templugs we've had stuck in holes at the end of each test since we've adopted this procedure has dropped markedly.

For those people that are wondering how we got the M1.6 plugs out of tapped holes; we used a microscope and matched up the fracture surfaces between the handle and plug. We also used a "Lubricant" which included at one time or another mineral spirits, penetrating oils such as "Liquid Wrench" and non-destructive dye penetrants (particular success was had using dye penetrants intended for use with titanium).

After installing the Templug in the flat bottomed hole we retain the plug using a patch spot welded in place. We have learned, sometimes the hard way, that you need to keep your patch and base (specimen) materials compatible and installed in a manner that will not influence your test results. Foils can be obtained in virtually any metallic material made today. While 300 series stainless steel works fine on Inconel materials at lower (<1000°F) temperatures, above that we've had mixed results. However, we bought some Inconel 625 foil stock and are having excellent success. While it takes a bit of experience and practice, here are some guidelines and suggestions for installing the retaining patches:

1. Test specimen material and patch material should be compatible; 3.3., use stainless on steel or stainless steel, Inconel on high temperature nickel based alloys, aluminum foil (it works quite well) on aluminum and titanium on titanium.

2. Use as large a patch as you reasonably can without affecting the characteristics of the tests, 0.250 inch diameter should be a maximum.

3. Use as few spot welds as you can that will keep the patch in place. I like 6 to 8 on static hardware, and at least 8 on rotating (and loaded) installations. **Keep spotwelds as far away from the hole opening edge as is practical.**

4. Use as low an amperage setting as is practical. Spotwelds and patch should be easily peeled away and off the test specimen with minimal residue left on the part. To remove the patches we use files or de-burring knifes ground to a 20° chisel edge angle.

After removal of the patches, the Templugs are removed in the following sequence of steps:

The Happy Templug - Falls out when part is turned up-side down. Surprisingly, this happens quite often!

The Shy Templug - Can be removed with a magnet (we use a 0.5 pound BLOCK OF SAMARIUM-COBALT, $Sm_2Co_{17}$; Cost approximately $300.00 - $500.00). We extract 90% of the Templugs using a magnet.

In my experience there are two causes for a Templug being stuck in a hole. The first is an improperly machined hole, which is usually detectable at installation and should be corrected at that time (small hones work wonders), the second is oxidation. On every Templug exposed to 1000°F or higher, I have observed some degree of oxidation on its surface, most notable the crests of the threads - **the worst place you'd want it!** In general here is how I proceed in these cases:

1. Using a scribe, I try to wiggle it in the hole and get it loosened up. Sometimes, after working it enough, you can get it out with a magnet.

2. Next, I try tapping* specimen to loosen or if loose, shake it out. Do this in a clean open area as they simultaneously do come out, and fall on the floor. Now the problem reverts to finding a "BB in a boxcar".

3. Failing at that, I suspend part in an ultrasonic tank of mineral spirits or penetrate fluid of some sort. I leave it in the tank for 30 minutes before I give up. One thing to note here, is that this last step usually works fairly well.

**HAPPY TEMPLUGGING!**

## Credits:

The preceding notes were prepared by Mr. LaVern Raabe, Speaker for TEI's 1996 **TEMPLUG** Round Table. Mr. Raabe is currently the Lead Engineer for the Advanced Concepts Division at Williams International in Walled Lake Michigan. We thought that the information contained would be very useful for user's of TEMPLUGS, so it was included into our User's Manual.

---

* Usually requires as big a hammer and as hard a blow as one can get away with.