An Issue in Time to Delamination (T_{260}) Testing for PCBs

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Abstract

It has been reported by several laboratories that the time to delamination or decomposition of a printed circuit board specimen at 260°C decreases with the specimen thickness. A temperature gradient across the thickness of the sample within the furnace of the Thermomechanical Analyzer (TMA) was the suspected cause. Testing laminate specimens with embedded thermocouples, the temperature gradients within two major brands of TMAs and at several laboratories was determined to be approximately 2.5 to 3°C per millimeter. This temperature gradient results in a 20°C difference between the top and bottom of a 7 mm thick specimen. Modifications of the T_{260} test parameters, such as thermocouple location during the test and thermocouple calibration procedure are recommended.

Introduction

This study focuses on the IPC-TM-650 Test Method 2.4.24.1, *Time to Delamination (TMA Method)*, for PCBs. The test is done in a TMA. A sample of PCB of the size 0.25 x 0.25 inches sits on a sample stage. A probe made of quartz contacts the top of the sample with light pressure, and records the sample movement along the thickness direction. The sample and probe are enclosed in a furnace chamber where the temperature is controlled to ramp at 10°C/min to 260°C and then dwell at 260°C. When an event occurs, such as delamination, cracking, moisture release, stress relaxation, or decomposition, a sudden movement of the sample surface will be detected. The time from the point when the chamber reaches 260°C to the failure event is defined as the time to delamination. This test is sometimes called "T_{260}". The T_{260} test is often used to characterize the thermal reliability of PCB during assembly and rework operations.

It is observed that the time to delamination decreases with PCB test sample thickness. A couple of examples are shown in Figure 1. A temperature gradient across the thickness of the sample within the TMA furnace chamber was the suspected cause. The thermocouple in the TMA chamber is located near the top of the sample stage or the bottom of the sample. When the bottom of the sample is at 260°C, the top of the sample may reach a higher temperature.

Experiments and Results

To verify if the temperature gradient in the TMA chamber causes the variation of the time to delamination shown in Figure 1, we decided to measure the temperature gradient. A two-layer laminate of 8 mm thick was made with a high Tg FR-4 and one-ounce Cu. The Cu-layers were on the top and bottom surfaces. Two tiny thermocouples of 3-mil diameter from Omega Engineering, Inc. were attached to the laminate sample near its top and bottom surfaces, as shown in Figure 2. To attach the tiny thermocouples onto the testing sample, two holes were drilled and the thermocouples were fixed with a high temperature epoxy.

A regular T260 test was conducted on the sample with embedded thermocouples, according to IPC-TM-650 Test Method 2.4.24.1. The temperature readings were recorded from four thermocouples (TCs): (1) TC of the TMA instrument, which was located near the top of the sample stage or the bottom surface of the sample; (2) embedded TC attached near the bottom of the sample; (3) embedded TC attached near the top of the sample; and (4) TC in air inside the TMA chamber, as shown in Figure 2.

Figure 3(a) plots the temperature readings. At ambient temperature, the readings of the four TCs were about the same. As the temperature increases, the readings started to differ, and the difference increased with the temperature. When the TMA TC read 260°C, the TC near the sample bottom read 264°C, and the TC near the sample top read 283°C. The sample thickness was about 0.3 inch or 7.6mm, therefore the temperature gradient was approximately 3°C/mm.

Figure 3(b) shows the results of an almost identical test to the test shown in Figure 3(a). The difference is that the testing sample was ground to remove the Cu layers on its bottom and top surfaces. The temperature readings in this test were the same as that in Figure 3(a). The two one-ounce Cu layers on the top and bottom did not make noticeable differences in the temperature gradient within the test sample.

Another measurement was conducted to determine the temperature gradient inside the TMA chamber without a test sample. As shown in Figure 4, four TCs were located at the different heights inside the temperature chamber, 0.06" (1.5mm), 0.3" (7.6mm), 0.5" (12.7mm), and 0.68" (17.3mm). Figure 5(a) plotted the temperature readings, as the TMA went through a T260 temperature profile. Notice that the TC at the 300 mil height read 283°C, the same value with a laminate sample on the stage in Figures 3(a) and (b). This indicates that the laminate was a very poor thermal conductor that did not affect the temperature gradient.

Figure 5(b) plots the temperature reading as the function of the TC location. It seems that the temperature gradient decreases gradually with the height inside the TMA chamber.

An aluminum sample with TCs taped to the side was used to measure the temperature gradient within a thermally conductive sample, as shown in Figure 6(a). The results, Figure 6(b), are that there was little temperature difference (~0.5C) between the top and bottom of the Al sample during heating. But during the dwell at 260°C, there was 5.6°C temperature range across the TC readings.

The above tests were conducted in a TMA from one of the two major brands of the instrument. To see if the temperature gradient observed in the above tests is a general phenomenon, the laminate samples with embedded TCs were sent to three different laboratories and tested in TMAs made by both major vendors. The results are that the values of the temperature gradient within the laminates are between 2.5 to 3°C/mm.

Discussion

The temperature gradient within a laminate sample during the T_{260} test in a TMA will result in a reduction of the time to delamination with increasing laminate sample thickness. Assuming that there is a sample with the thickness of 300 mil (7.62 mm). The temperature difference between the top and the bottom of the sample is 3°C/mm * 7.62 mm = 23°C. Therefore, during the initial temperature ramp of the T_{260} test, when the bottom the sample reaches 237°C, the top of the sample is at 260°C. It will then take 2.3 minutes more for the bottom of the sample to change from 237°C to 260°C, because of the ramping rate of 10°C/min. By then the top of the sample will have been above the 260°C for 2.3 min. It is deduced that the time to delamination of the sample with the thickness of 7.62 mm is at least 2.3 min shorter than that of the sample with zero thickness. The product of sample thickness (h) and temperature gradient (g), divided by the ramping rate (r), i.e. h * g / r, is the minimum reduction of the time to delamination due to the sample thickness. For the ramping rate of 10°C/min, and the temperature gradient of 2.5 to 3°C/mm, the minimum reduction of the time (in min) to delamination is 0.25 or 0.3 times the sample thickness (in mm).

There are at least a couple of ways to avoid overheating a thick sample. One is to change the TMA thermocouple location, from the bottom of the sample to the top of the sample. So when the top of the sample reaches 260°C, the bottom of the sample will be cooler than 260°C. To use this method, the TMA thermocouple should be on the bottom of the sample or the top of the sample stage when one performs the thermocouple calibration procedure.

The other way is to slice a thick sample into several thin pieces, and test thin samples. There are commonly two failure mechanisms when a sample is tested in T_{260}, delamination at an interface (between Cu and resin, or between glass and resin), or thermal decomposition (sample becomes charcoal). The thermal decomposition is caused mostly by heat, which breaks the primary covalent bonds of epoxy resin. For this failure the sliced thin samples should fail at the same time duration as the original thick sample. The interfacial delamination is caused by the reduction of the bonding strength due to heat, and by the stress. The stress may be introduced due to the CTE mismatch between Cu and epoxy resin and due to the temperature gradient inside the sample. Even for a uniform material, a temperature gradient produces strains, therefore stresses inside the material. For the delamination, the sliced thin samples may have longer time to delamination than the original thick sample.

The thermal gradient in a TMA furnace chamber may be reduced by adjusting gas flow, or by optimizing the furnace control parameters, or even by a new furnace design. Suppose we could get a TMA furnace with a perfectly uniform temperature, or zero temperature gradient. Is it what we want? During component attachment processes, especially wave soldering process, a PCB experiences a temperature gradient. The side facing solder pot is hot; the side away from solder pot is less hot. The temperature gradient produces strains and stresses inside the PCB. If we want to use the T_{260} test to evaluate the thermal stability of a PCB during assembly processes, we may want to include some level of the temperature gradient inside TMA furnace. What the ideal T_{260} testing parameters are is an interesting subject, but is beyond the scope of this paper.

Conclusion

The temperature gradient across the thickness of a FR-4 laminate in a TMA furnace during the T_{260} test is about 2.5 to 3°C/mm. The temperature gradient reduces the time to delamination for thick samples. The minimum reduction of the time (in min) to delamination is 0.25 or 0.3 times the sample thickness (in mm).

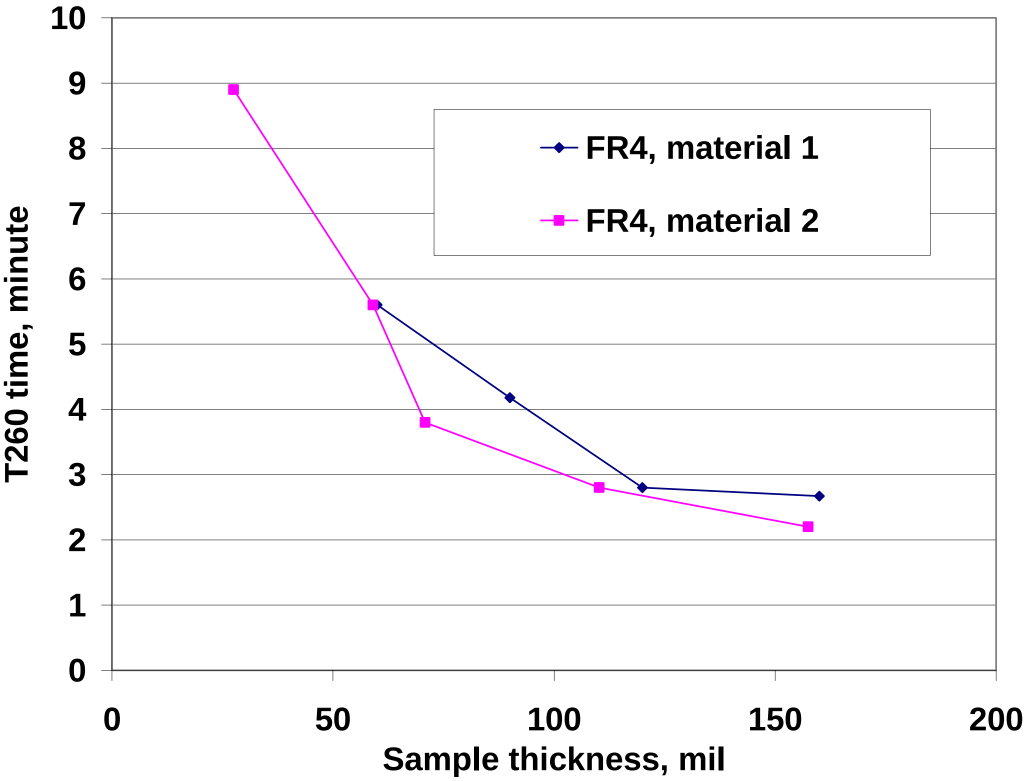


Figure 1: The time to delamination, determined by TMA, of a printed circuit board specimen at 260°C decreases with the specimen thickness, reported by several labs and with several FR4 materials. Here are a couple of examples.

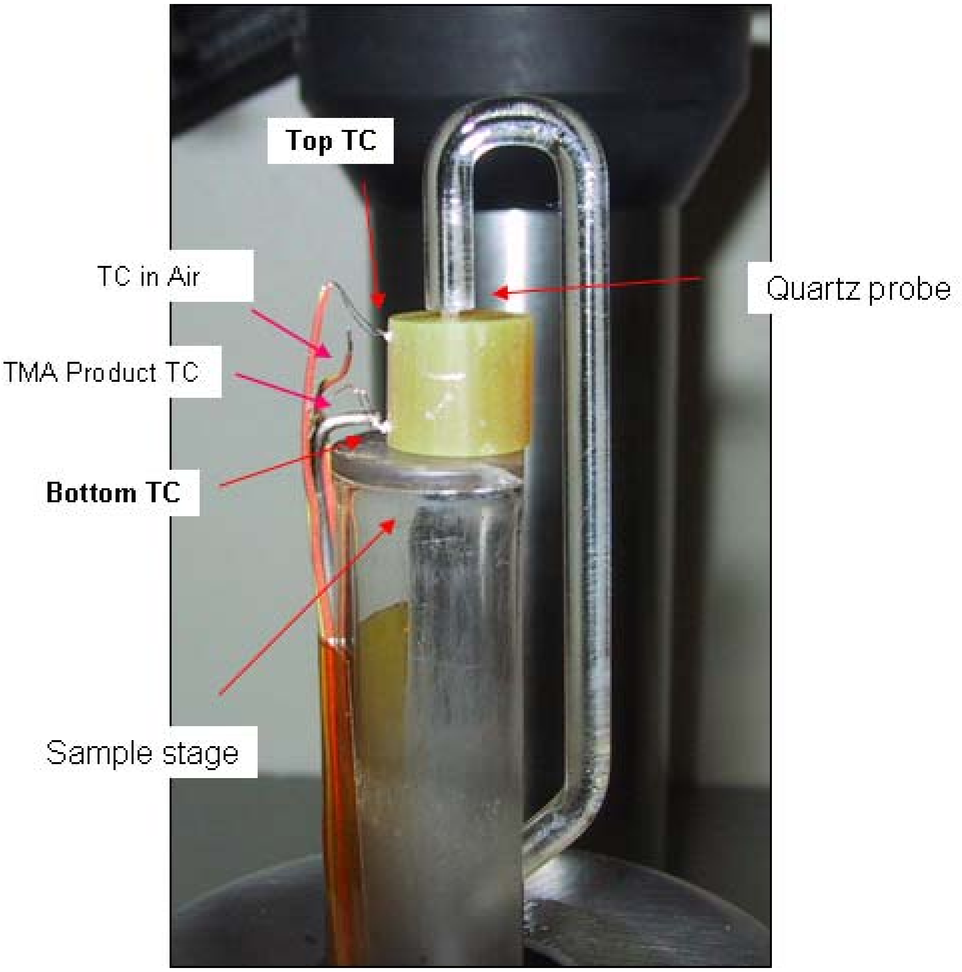
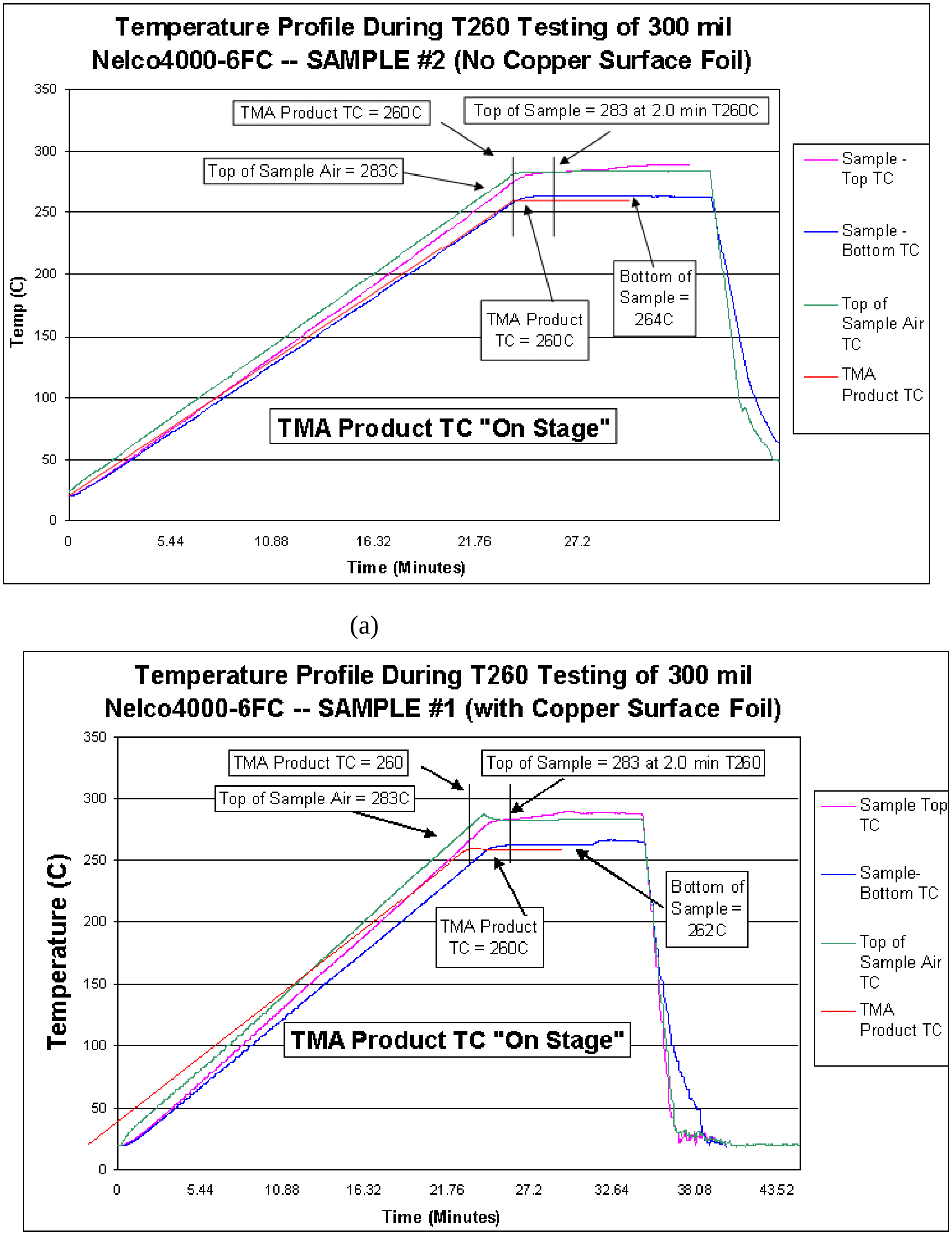


Figure 2: The test setup for measuring the temperature gradient in a laminate sample. Two tiny thermocouples (TCs) are embedded in the laminate.



(a)

(b)

Figure 3: Temperature readings from the thermocouples embedded in a laminate samples and the TMA instrument TC, and a TC in air inside a TMA furnace chamber, during T260 tests.

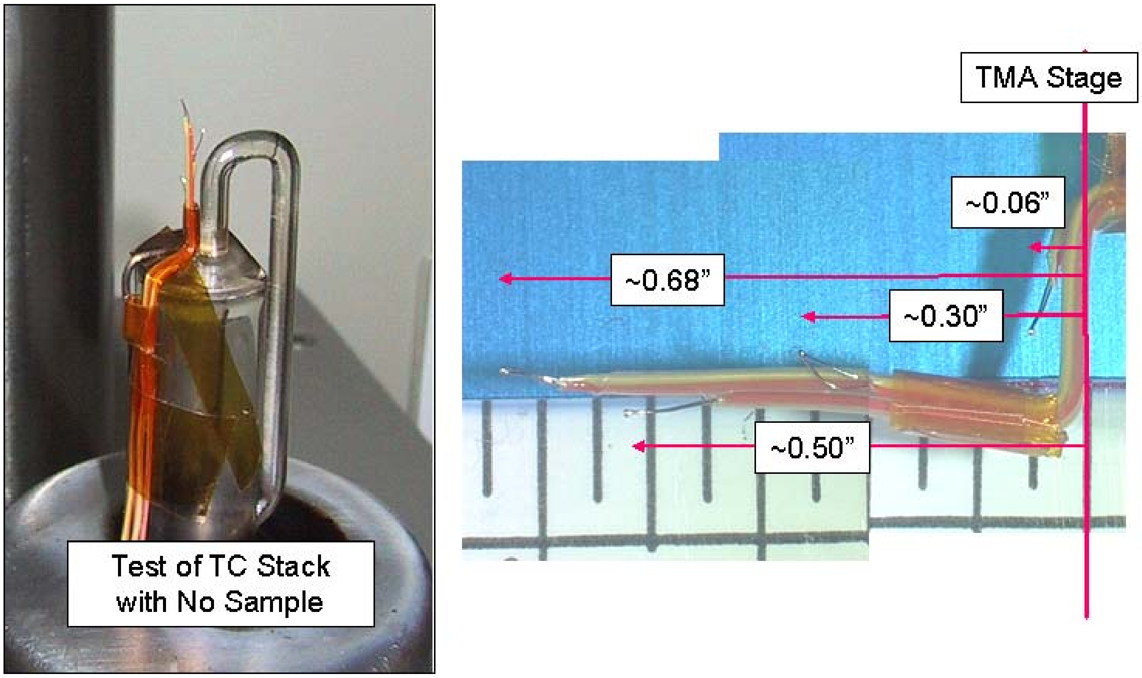


Figure 4: The setup to measure the thermal gradient inside TMA furnace chamber without testing sample. Four thermocouples are located at different heights.

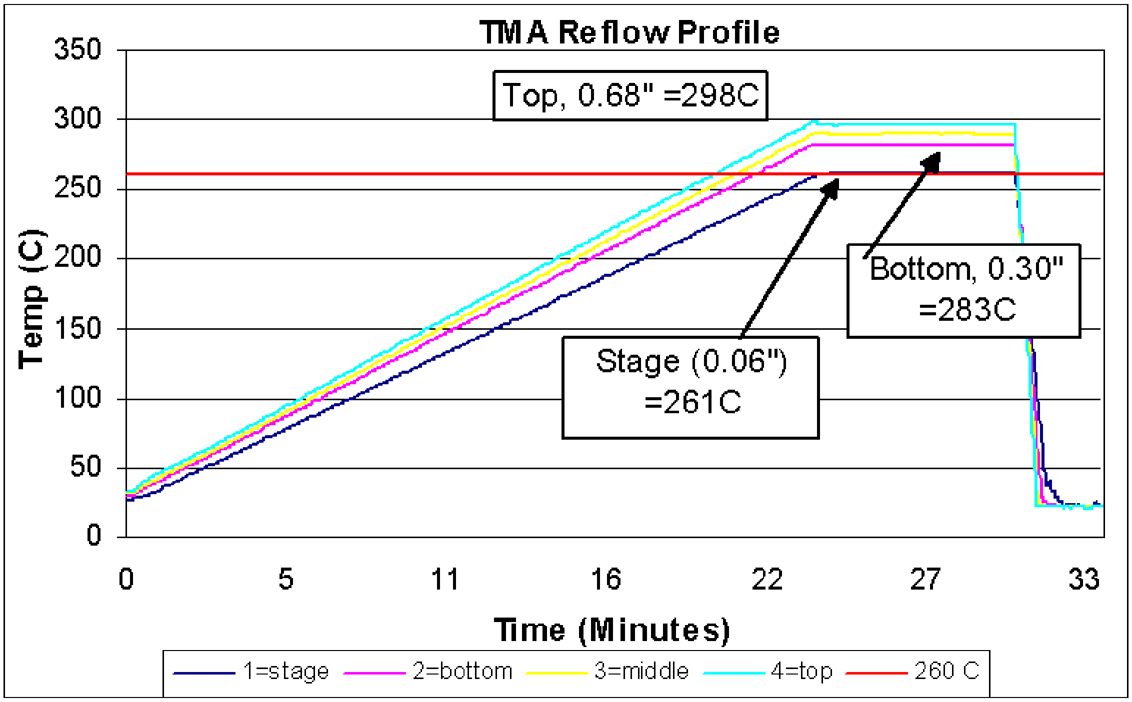


Figure 5(a): Temperature readings from the four thermocouples shown in Figure 4 during a T260 test run without sample inside the furnace chamber.

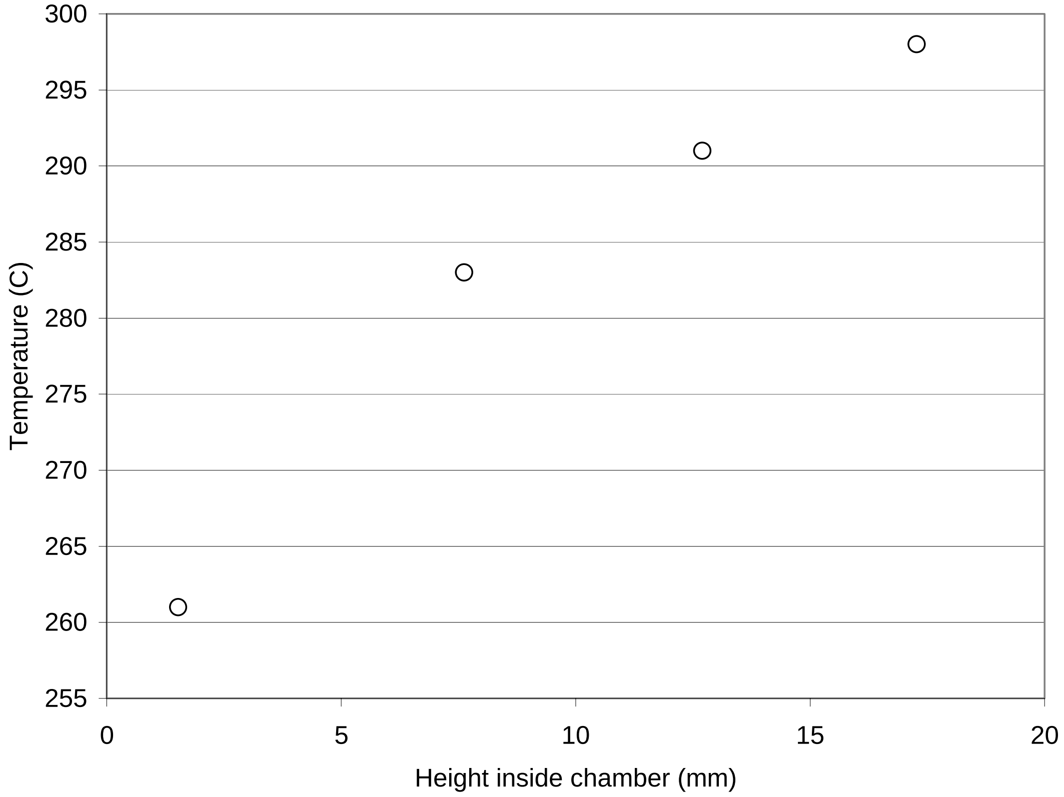


Figure 5(b): Peak temperatures of the four thermocouples shown in Figure 4, during a T260 test run without sample inside the furnace chamber.

Figure 6(a): An aluminum sample with TCs taped to the side was used to measure the temperature gradient within the sample.

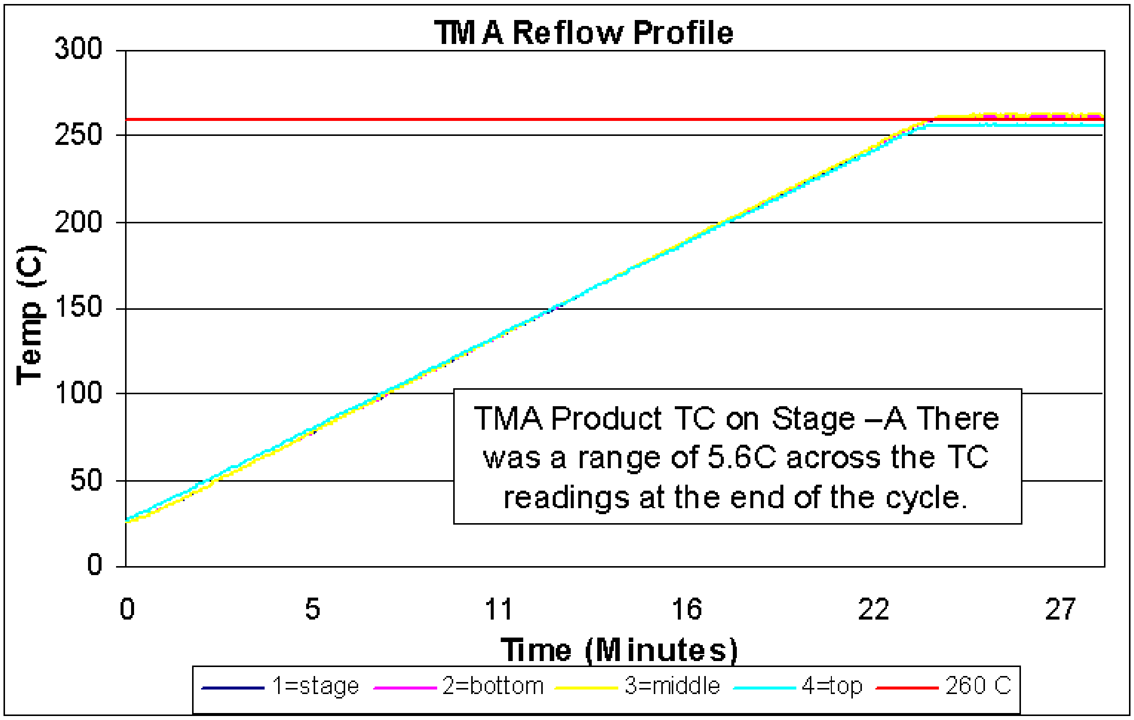


Figure 6(b): Temperature readings from the thermocouples shown in Figure 6(a), during a T260 test of the aluminum stud shown in Figure 6(a).

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