

Determination of Skin Burn Temperature Limits for Insulative Coatings Used for Personnel Protection

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ABSTRACT

Workers often perform tasks on high temperature equipment and piping. As they move about this equipment they may have unintentional contact with the hot surfaces resulting in burns to the skin. Thermal insulation is generally installed on metallic equipment at 60°C (140°F) or higher for personnel protection (PP). Insulative coatings are an alternative to the use of traditional insulation for PP where strict heat retention is not required. Although the external surface of the insulative coating may heat up to temperatures greater than 60°C, it can have a threshold burn temperature that is higher than for the metal substrate because of the coating's lower thermal conductivity. This is a well known fact, but the perception of many plant personnel is that the coating surface must also be less than 60°C. This report presents work that validates the use of an insulative coating for PP using accepted instrumentation in accordance with ASTM C1055, C1057, and ISO 13732-1. Test variables included coating thickness, metal substrate temperature, ambient air temperature, surface roughness and hot vs. ambient coating application. In addition to determination of the burn thresholds, the results confirm that higher surface temperatures than 60°C are allowed for insulative coatings.

Key words: Insulative coatings, thermesthesiometer, personnel protection, skin burn temperatures, burn temperature limits

INTRODUCTION

In most industrial manufacturing and petro-chemical plants, there is a large number of equipment and piping operating at high temperatures. Personnel often perform tasks, maintenance or inspection on this equipment and piping. As personnel move near and around this equipment they may have unintentional contact with the hot surfaces that may result in burns to the skin. As a result, thermal insulation is generally installed on metallic equipment and piping at 60°C (140°F) or higher for personnel protection (in addition to minimizing heat loss).

The Occupational Safety and Health Administration (established in 1971) typically addresses safety issues for employees. However, it does not address temperature limits for hot surfaces other than stating that workers must be protected from industrial hazards such as burns by the use of engineering controls or with the provision of personal protective equipment¹. Instead, it refers to ASTM C1055² and C1057³ (which were first approved in 1986) for determining temperature limits for hot surfaces that personnel may come into contact with.

For any hot surface, the procedure for determining temperature limits in ASTM C1055 is to first choose the maximum level of acceptable injury and a maximum contact time. ASTM C1055 recommends the use of a first-degree burn as the maximum injury level and a contact time of 5 seconds for industrial situations. These two criteria are the accepted rule in most industrial plants. According to ASTM C1055, the maximum allowable surface temperature for metallic objects using these two criteria is about 60°C (140°F). So the basis of the general industry rule of insulating equipment/piping above 60°C/140°F is ASTM C1055. Another standard similar to ASTM C 1055/1057 is ISO 13732-1⁴. It proposes a 4 second contact time for unintentional contact. The basis for these standards came about after reviewing many studies that determined skin temperatures at which burns occur and the severity of the burns with different contact times.

The possibility of a burn occurring depends on three primary factors: surface temperature, thermal properties of the hot surface, and contact time of the skin to the surface. There is a distinction between an object's surface temperature and the temperature of the skin after touching that object. The reader must not confuse the two. Depending on the type of material of the hot object, the skin temperature can be close or significantly cooler, after the 5-second contact time, than the temperature of the hot surface. For metal objects (which typically have high thermal conductivities) the heat transfer is rapid and will heat the skin to within a few degrees of the temperature of the metal surface within the 5-second rule. For lower conducting materials such as wood, plastic and insulative coatings, the thermal conduction is slower and the skin temperature may be significantly lower than the object's surface temperature after a contact time of 5 seconds.

For metals which have high thermal conductivities, The temperature at which a burn will occur depends on the metal's surface temperature and contact time. For surface temperatures below 44°C (111°F), no burns will occur for up to 6 hours of contact time¹. As metal temperatures increase above 44°C, the contact time resulting in a 1st degree burn decreases dramatically. Skin in contact with metal at a temperature of about 60°C (140°F) has only a 5 second contact time at which a first-degree burn will occur.

What if a metal surface is coated with a material that is non-metallic in nature? Is the surface temperature of that material also required to be less than 60°C (140°F)? The answer is no, as explained in both ASTM C 1055 and ISO 13732-1. The 60°C (140°F) limit for a 5 second contact time generally only applies to metals. Materials with lower thermal conducting properties will transfer less heat per time than for metals. As a result, insulative coatings can have higher surface temperature burn-limits than for metals^{2,3,4,5,6,7}. However, many end-users in industrial plants still have the mistaken perception that piping and equipment coated with non-metallic coatings must have surface temperatures of less than 60°C on the coated surface also. This perception places undue restrictions on the use of materials that are not metallic but offer temperature reduction far within the means of personnel protection and this is worth examining by industrial hygiene personnel.

What is needed is an examination of definitions and specifications of the ASTM and ISO documents and how surface temperature limits are determined for non-metallic materials and most specifically for the use of insulative coatings used for personnel protection. A cognitive understanding and testing of coating performance of this technology will help engineers and maintenance staff develop common guidelines and help to meet or exceed OSHA/ISO standards.

This paper examines the definitions and scientific test methods, used to evaluate a thermal insulation coating (Mascoat Industrial-DTI⁽¹⁾) using the ASTM/ISO tests. With this understanding, the benefits of insulative coatings can be fully realized/defined and their use can result in significant cost savings for most any application considering personnel protection.

In regards to a non metallic substrate, ASTM C1055 states that if the temperature is above that for the burn level/time criteria of 58°C (137°F), then:

"further analysis of the system is required using either the thermesthesiometer or an additional calculation as given in ASTM 1057."

This statement brings two things to light. The first is that calculations can be used to determine acceptable means of determining burn risk. The second and most important is the use of a thermesthesiometer (TM) as an alternative method to determine burn risk. The focus of this report therefore was to consider a TM as a consistent means of reproducible temperature evaluation in a controlled (laboratory) setting and to then refer back to the ASTM/ISO documents for means of acceptable criteria for determination of burn risk.

The TM instrument is used to simulate the temperature of the skin when the probe is placed onto a hot test surface for a given period of time. The TM temperature probe is made of a special silicone rubber that closely matches the thermal conductivity of skin and therefore simulates the characteristics of skin. A small thermocouple is embedded in the silicone at about 75 μ (3 mils) from the contact surface. This is about the same depth in skin where the dermal layer (live cells) starts.

¹ Trademark.

ISO 13732-1 states that thermal modeling of burn temperatures vs. surface temperatures for very low thermal conducting materials generally gives higher burn temperature values. It then concludes that the calculations do not lead to valid results. Therefore, for insulative coatings, having low thermal conductivities, thermesthesiometer testing by definition would be more appropriate than modeling. In addition, mathematical models cannot be used if the thermal properties of thermal conductivity, specific heat and density have not been determined for the material.

The TM test instrument was developed by L. A. Marzetta in 1974 at the National Institute of Standards and Technology (NIST). Marzetta conducted an extensive study to assess the performance of the TM and to set-up appropriate calibration procedures. He states that, "If used correctly, it appears to provide a reasonably accurate estimate of contact (skin) temperature".⁵ Marzetta claimed in the patent for this instrument that the accuracy is $\pm 3^{\circ}\text{C}$ within the operating range (for skin temperature simulations) of $45 - 75^{\circ}\text{C}$ ($113 - 167^{\circ}\text{F}$).⁸

For the basis of testing in this report, and as per the ASTM/ISO standards, the author selected the burn criteria of a 1st degree burn limit, a skin temperature limit of 60°C (137°F) and a contact time of 5 seconds. Longer contact times would result in more severe burns or would require a lower skin temperature to limit the burn to a first degree. Allowing higher skin temperatures above 60°C (140°F), would also result in more severe burns or would require shorter contact times below 5 seconds.

The burn criteria (as proposed in ASTM C 1055) of a 1st degree burn as maximum injury level and a 5 second contact time, will be referred in the remainder of this report as Personnel Protection 5 seconds or PP/5s. With these criteria, the maximum allowable skin temperature is 58°C (137°F). The criteria for a maximum injury level of a 1st degree burn and a 4 second contact time (as proposed in ISO 13732-1) will be referred to as PP/4s with a maximum skin temperature of 59°C (138°F). One clarification: a PP/5s or PP/4s refers to the ASTM or ISO criteria, while a TM/5s refers to a particular thermesthesiometer temperature reading at 5 seconds contact time for this particular report.

This report presents work done to validate the use of an acrylic water-borne insulative coating for personnel protection using the TM instrument in accordance with ASTM C1055, C1057 and ISO 13732-1. This coating has ceramic and proprietary fillers that result in a low thermal conductivity of approximately $0.07 \text{ W/M}^{\circ}\text{K}$.

The coating was evaluated with several variables such as coating thickness, metal substrate temperature, ambient air temperature, surface roughness and hot vs. ambient coating application. In addition, the surface temperature of the coating was measured with both an Infra-red (IR) pyrometer and a digital contact thermocouple probe to better understand the differences between these two instruments. The results confirm that much higher surface temperatures, than 58°C (137°F), are allowed for insulative coatings for personnel protection purposes. In addition, the worst-case burn temperature thresholds were determined for various coating thicknesses.

EXPERIMENTAL PROCEDURE

Test Panel Preparation

Eight carbon steel test panels with dimensions of 10cm x 20cm x 6mm thick (4 in x 8 in x 1/4 in) were cleaned to an SSPC SP3. No corrosion protective primer was applied because the intent was to evaluate the insulative coating only. A hole was drilled in the center of one 20 cm (8 inch) side of each panel to a depth of about 2.5 cm (1 inch) to allow insertion of a sheathed thermocouple used to regulate the test panel temperature. On panels 1-5, the insulative coating was applied with approximately 500 microns (20 mils) per coat. The total coating thicknesses ranged from 1 - 5 mm (40 - 200 mils) in increments of 1 mm (40 mils). Panel # 6 was heated to 149°C (300°F) during the entire coating application with 3 mm (120 mils) to simulate hot in-service applications. On panel # 7, the last coat was applied in a very rough texture or profile to compare TM test results to the relatively smooth surface on panel # 3. Panel # eight was a bare steel panel with no coating and used as a control.

After application of each coat, the test panels were placed into an oven at about 54°C (130°F) to speed the drying time. After final coating application, the coating thickness was measured with a digital thickness gauge and all panels (except for panel #7) abraded until the nominal coating thickness was obtained. The panels were then cured in an oven at 149°C (300°F) for 7 days.

Prior to testing, the effect of various degrees of surface roughness on the TM readings was unknown. It was speculated that rough surfaces could result in lower TM readings because only the peaks are touching the TM probe and therefore there is less conduction to the probe. Therefore, close attention was given to the surface profile of the coatings until more was known about its effects on TM readings. A Mitotoyo SJ-210 surface profilometer was used to measure the surface profile. Profile readings of the coating surfaces, as is, without any abrading ranged from 6 - 10 microns (250 to 400 micro-inches). The intent was to keep the profiles of test samples between 5-8 microns (200 - 300μ inches), by abrading with 150 grit paper, to minimize variability of test results due to the varying profiles. The profile on panel # 7 was > 0.35mm (>14 mils) (the upper limit of the profilometer was 0.35 mm).

Thermesthesiometer Test Procedures

The objective was to determine the simulated skin temperatures for contact times of 0-10 seconds, on heated carbon steel substrates, coated with an insulative coating and in accordance with ASTM 1055/1057 and ISO 13732-1. From these results, the burn temperature limits could be determined for the various coating thicknesses.

Prior to testing, ambient temperature readings were taken in the room. For a solid baseline of the panel internal temperature, a thermocouple was inserted into the hole drilled into the side of the panel and connected to a PID thermal controller to regulate the steel temperature to a desired setting. Each panel was tested at various metal substrate temperatures, in 5 or 28°C (10 or 50°F) increments, in the ranges listed in Table 1 for each coating thickness. For each substrate temperature used, the corresponding surface temperature of the coating was measured and compared.

Each panel was heated on a hot plate (See Figure 1) to the desired temperature and held for a

minimum of 5 minutes to equilibrate or until the temperature readings on the coating surface had leveled off. Surface temperatures on the coating were measured in the center of the test panel with an IR pyrometer and a digital thermometer contact probe, after equilibration of the contact probe at the desired temperature (See Figure 2 for photos of these devices). The IR pyrometer was calibrated using a test panel coated with an insulative coating placed in an oven and equilibrated at a known temperature. The IR pyrometer emissivity settings were adjusted to obtain a pyrometer reading that was the same as the oven temperature. For this insulative coating, the emissivity that gave the closest readings to the actual temperatures was a value of 0.97.



Figure 1. Test Set-up with TM probe on Center of Test Panel over a Hot Plate



Figure 2. Photos of Temperature Probes and sensors

To determine reproducibility of TM temperature readings on the first panel, the tests were performed in duplicate for each of seven substrate temperatures measured. For all three measuring devices: IR pyrometer, contact probe and TM probe, the average variability was only about $\pm 0.3^{\circ}\text{C}$ (0.5°F) between the two tests for each device.

The TM probe was brought to an initial temperature of 32°C (90°F) prior to each test to simulate initial skin temperature. The TM test was started by manually lowering the probe onto the coated surface and a force of approximately 18-22N (4-5 lbs) was used to obtain good contact with the surface. The exposure time was a minimum of 10 sec from the time a temperature of 40°C (104°F) was reached by the TM probe. So time zero began at 40°C. The TM temperatures vs. time were recorded digitally with a reading every 0.1 seconds. The test apparatus was placed such that it was not directly under an AC vent. In this test there was little or no air movement over the panels. For this work PP/5s and PP/4s criteria (as stated above) were used to determine the maximum burn temperatures for the insulative coatings.

A bare steel (uncoated) panel was tested with ambient air temperatures of 19°C (66°F) to compare results to the coated panels. Tests were performed at metal temperatures ranging from 60 to 149°C (140 to 300°F). In addition, the test for panel # 3 was repeated at an ambient temperature of 38°C (100°F) with metal temperatures of 121, 149 and 177°C (250, 300 and 350°F) to determine worst-case burn temperature limits.

Table 1. Test Panel Data of an Acrylic Waterborne Insulative Coating

Panel #	Coating Nominal Thickness (mm/mils)	Test Temperature Range (°F)	Type Application
1	1.0 / 40	140-350	ambient application
2	2.0 / 80	140-400	ambient application
3	3.0 / 120	180-400	ambient application
4	4.0 / 160	200-400	ambient application
5	5.0 / 200	200-400	ambient application
6	3.0 / 120	180-350	application on metal panel at 300°F
7	3.0 / 120	180-350	ambient application with very rough surface
8	0 (bare steel)	140-300	no coating

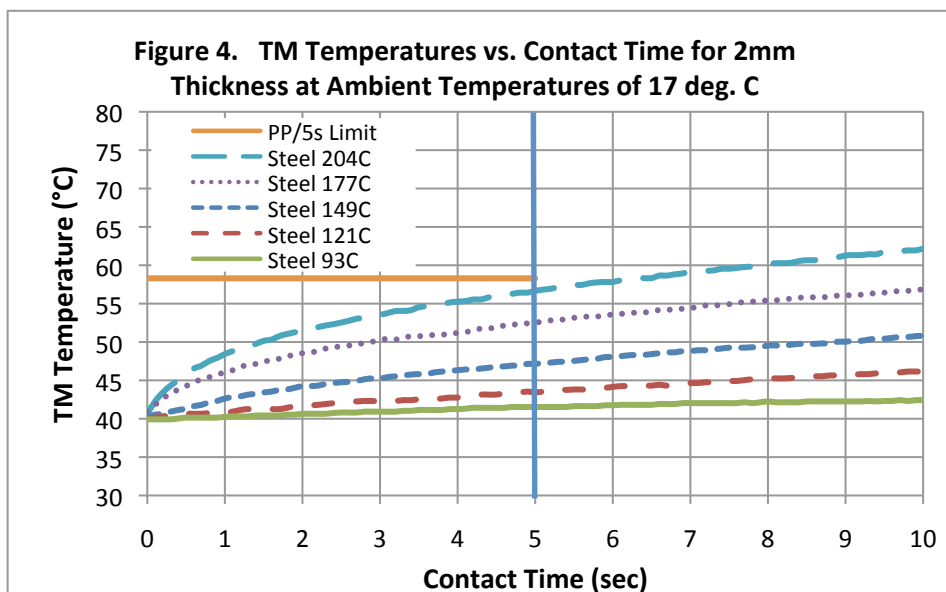
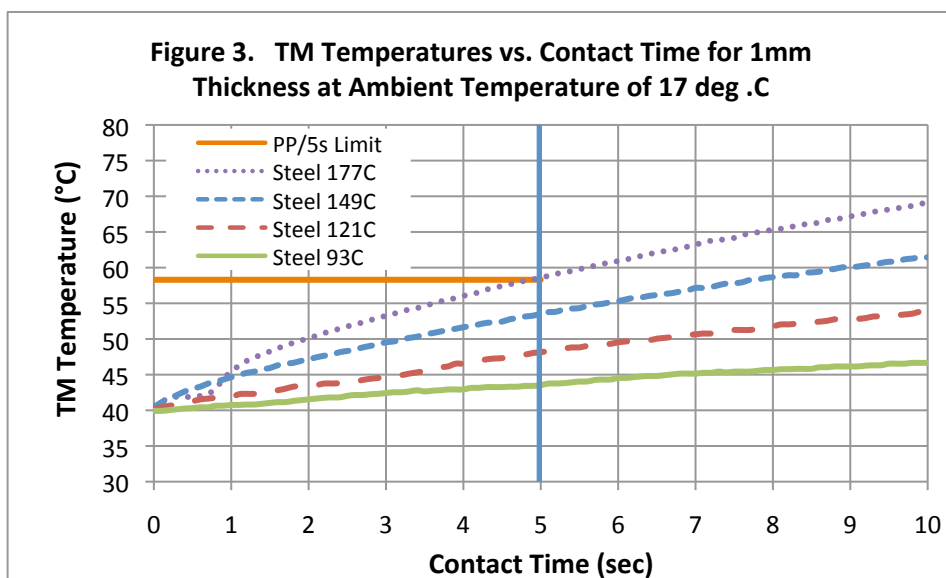
RESULTS AND DISCUSSION

PP/5s and PP/4s Surface Temperature Limits for the Insulated Coating

As stated in the introduction, the skin burn threshold temperature is 58°C (137°F) for a contact time of 5 seconds and 59°C (138°F) for a 4 second contact time. The actual skin temperature that is reached during a contact with an insulative coating depends on several variables:

1. Thickness of the coating
2. Metal substrate temperature
3. Coating surface temperature
4. Ambient air temperature
5. Thermal characteristics of the coating
6. Air movement over the hot surface (Both standards specify that the test materials should be tested under worst-case conditions. Having no air movement across the panel surface will result in higher surface temperatures and be a worst-case condition, all tests were therefore performed with no forced air movement over the test panels.)

The results for coating thicknesses of 1 and 2 mm (40 and 80 mils) are shown in Figures 3 and 4 for comparison. The results for coating thicknesses of 3, 4 and 5 mm (120, 160 and 200 mils) (not shown in this report) showed similar graphs but at progressively decreasing TM temperatures. Figures 3 and 4 show the TM temperatures vs. the contact time with average ambient temperatures of 62°F. The only coating thickness that exceeded the PP/5s criteria was for a 1mm (40 mil) thickness at the highest substrate temperature tested 177°C (350°F). All other coating thicknesses tested did not exceed the PP/5s criteria at any metal temperatures up to 204°C (400°F) which is the temperature limit of the coating.



As expected, with increasing coating thickness, TM/5s temperatures decrease (see Table 2). By extrapolation between the 1 and 2 mm (40 and 80 mil) coatings, the thickness at which the PP/5s criteria is exceeded with a substrate temperature at the temperature limit of the coating (204°C, 400°F), is 1.8 mm (72 mils) thickness. This means that at ambient temperatures of 17°C/62°F and

no wind, a coating thickness of 1.8 mm (72 mils) meets ASTM C1055 up to the temperature limit of the coating. (However, an ambient temperature of 17°C (62°F) is not the worst-case scenario, so the 1.8 mm (72 mils) is corrected below for ambient conditions at 38°C (100°F.)

Table 2. TM/5s Temperatures for Various Coating Thickness and Substrate Temperatures Measured at Ambient Temperatures of 17°C (62°F)

Coating Thickness (mm/mils)	TM/5s Temperatures (°C/°F) at Various Metal Substrate Temperatures				
	93°C (200°F)	121°C (250°F)	149°C (300°F)	177°C (350°F)	204°C (400°F)
1 / 40	43/110	48/119	53/128	59/138	Not tested
2 / 80	42/107	43/110	47/117	53/127	57/134
3 / 120	41/105	43/110	46/115	47/117	51/123
4 / 160	41/105	42/107	44/111	47/116	51/123
5 / 200	41/105	41/106	42/108	44/112	48/118

Number in bold italic type means the PP/5s limit was reached or exceeded

For a given substrate temperature, the TM/4s temperature readings are slightly lower than readings for TM/5s temperatures. However, with the shorter contact time of 4 seconds, the substrate and coating surface temperatures are allowed to be somewhat higher for the PP/4s limit than for the PP/5s limit. For example, with a 1mm (40 mil) coating thickness, the PP/4s substrate temperature limit is 191°C (373°F) compared to 177°C (350°F) for the PP/5s limit. Because the 5 second contact time is more conservative and gives a more conservative (lower) temperature limit, only the results for the PP/5s limits are given in this report.

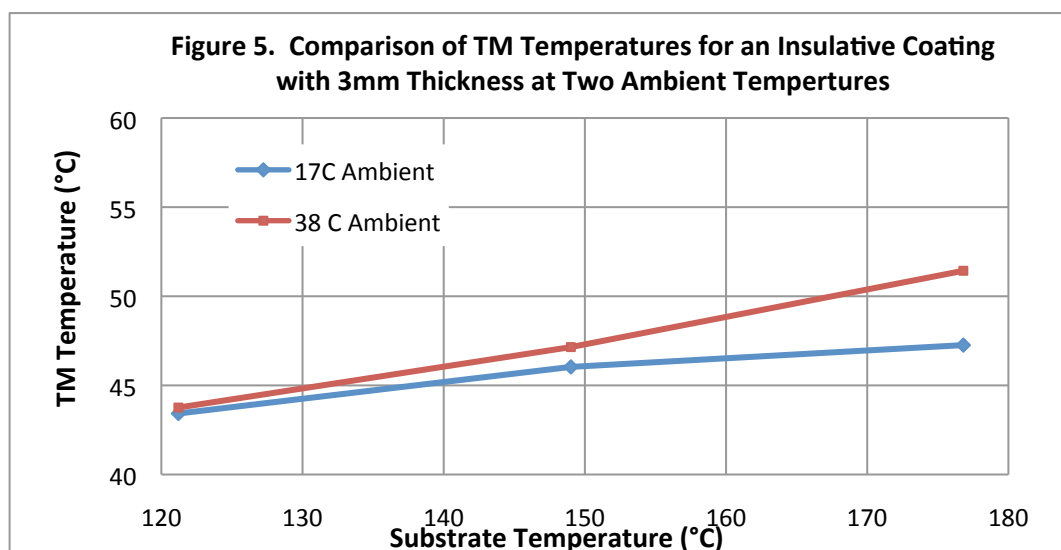
TM Temperatures Measured at Ambient Temperatures of 38°C (101°F) "Worst-Case"

The TM tests for panel # 3 with 3 mm (120 mils) coating thickness were re-run for metal substrate temperatures of 121, 149 and 177°C (250, 300 and 350°F) at an average ambient temperature of 38°C (101°F). The purpose for this test was to determine the degree of increase in TM/5s temperatures compared to tests at 17°C (62°F) ambient temperatures. The results are shown in Figure 5. Hotter ambient air temperatures result in higher TM/5s temperatures. At substrate temperatures of 121, 149, 177 and 204°C (250, 300, 350 and 400°F), the increases in TM/5s temperatures are 0.6, 1.1, 4.4, and 5.6°C (1, 2, 8 and 10°F) respectively. Table 3 shows the corrected TM/5s temperatures for 38°C (101°F) ambient temperatures.

Table 3. TM/5s Temperatures for Various Coating Thicknesses and Substrate Temperatures Corrected for Ambient Air Temperatures of 38°C (101°F) "Worst-Case Situation"

Coating Thickness (mm/mils)	TM/5s Temperatures (°C/°F) at Various Metal Substrate Temperatures				
	93°C (200°F)	121°C (250°F)	149°C (300°F)	177°C (350°F)	204°C (400°F)
1 / 40	43/110	47/120	54/130	63/146	--
2 / 80	42/107	43/111	48/119	56/135	62/144
3 / 120	41/105	43/111	45/117	51/125	56/133
4 / 160	41/105	42/108	45/113	51/124	55/133
5 / 200	41/105	42/107	43/110	48/120	52/128

Numbers in bold italic type means the PP/5s limit was reached or exceeded



For hotter ambient air temperatures, two coating thicknesses of 1 and 2 mm (40 and 80 mils) reach the PP/5s limit and are highlighted in bold italic type in Table 3. The other three thicknesses have TM/5s temperatures still below the 58°C (137°F) limit.

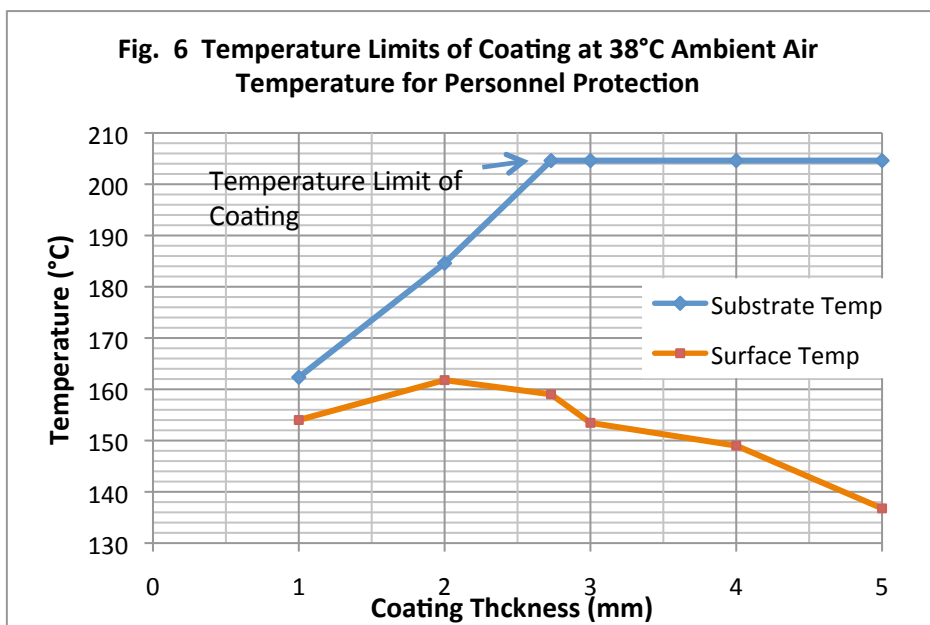
Table 4 summarizes the worst-case coating surface temperature limits for the coating when measured at 38°C (101°F) ambient air temperature. Extrapolating between 2 and 3 mm (80 and 120 mils), the coating thickness that reaches the PP/5s limit of 58°C (137°F) at a substrate temperature of 204°C (400°F) is 2.7 mm (109 mils). **In other words, at 2.7 mm (109 mils) thickness or greater, the insulative coating can be used for personal protection to the temperature limit of the insulative coating.**

Table 4. Worst-Case Temperature Limits for Insulative Coating at 38°C (101°F) Ambient Air Temp.

Coating Thickness (mm/mils)	Substrate Temp Limit (°C / °F)	Approximate Surface Temperature limit by IR Pyrometer (°C/°F)	TM/5s Temp (°C/°F)**
1 / 40	162 / 324	154 / 309	58 / 137
2 / 80	184 / 364	162 / 323	58 / 137
2.7 / 109	204* / 400	159 / 318	58 / 137
3 / 120	204* / 400	153 / 308	56 / 133
4 / 160	204* / 400	149 / 300	52 / 126
5 / 200	204* / 400	137 / 278	48 / 118

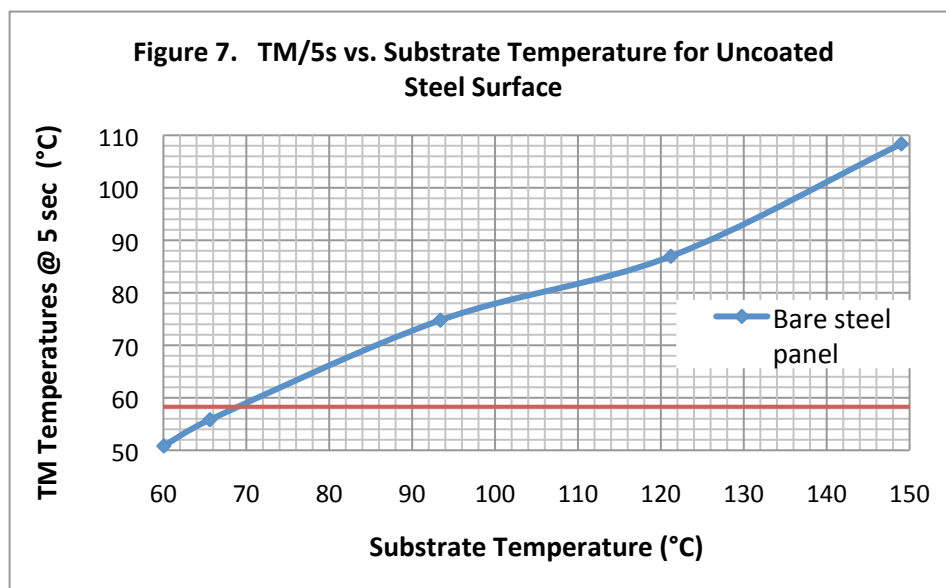
* Temperature limit of coating, ** PP/5s limit is 58°C (137°F)

Thicknesses less than 2.7 mm (109 mils) are limited by the PP/5s limit (as opposed to the temperature limit of the coating). These limits of the coating are also shown in Figure 6. Note that the surface temperature limits (as determined with the IR pyrometer) have values between 137 and 162°C (278 and 323°F) in the table. These temperatures seem high, but only because we are comparing our experiences with touching hot bare metal. The reader must keep in mind that hot surfaces for insulative coatings will not "feel" like those temperatures. This is because the insulative coatings conduct heat much slower than for metals. Also keep in mind that, by definition, a first degree burn will occur at these temperature limits.



TM/5s Temperatures for Bare Steel at Ambient Temperatures of 19°C (66°F)

A check was done using a bare carbon steel test panel to determine how close the TM results will be to the ISO and ASTM standards for bare metal which indicates the burn threshold is about 60°C (140°F). TM/5s temperatures were determined at 60, 66, 93, 121 and 149°C (140, 150, 200, 250 and 300°F) substrate temperatures with ambient air temperatures of 19°C (66°F) (See Figure 7). A contact probe was used to measure the metal surface temperature. The PP/5s limit of 58°C (137°F) was reached with a surface metal temperature of 69°C (156°F) which is slightly higher than expected.



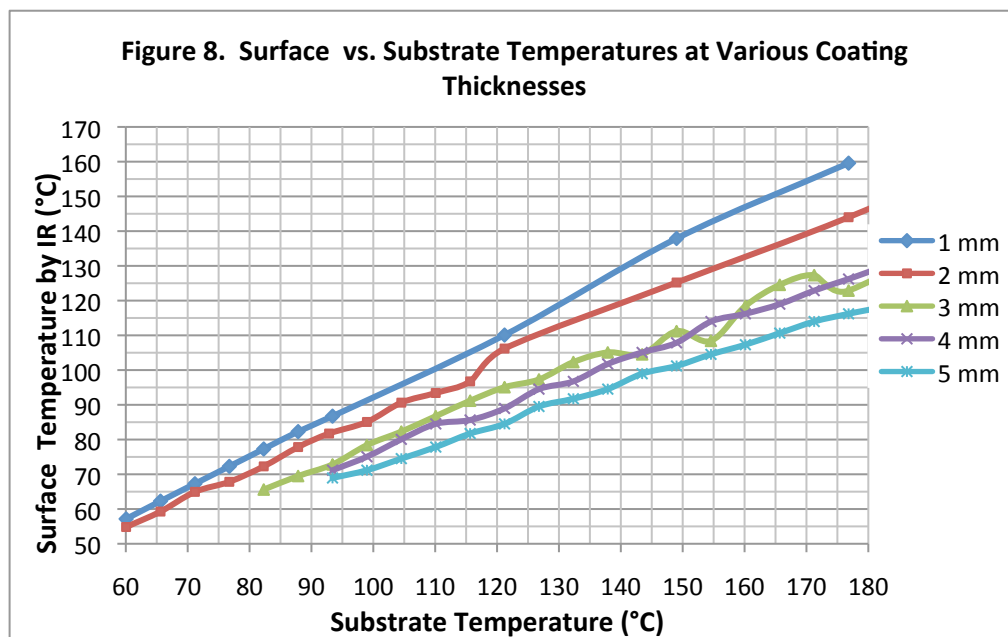
However, there are two reasons for this difference. First, the temperature of 60°C used in the standards is a generalization for all metals. Carbon steel does have a lower thermal conductivity than for some metals such as aluminum and bronze and would therefore have a slightly higher PP/5s than for those metals. Second, if the ambient temperature used in this test was at the worst-

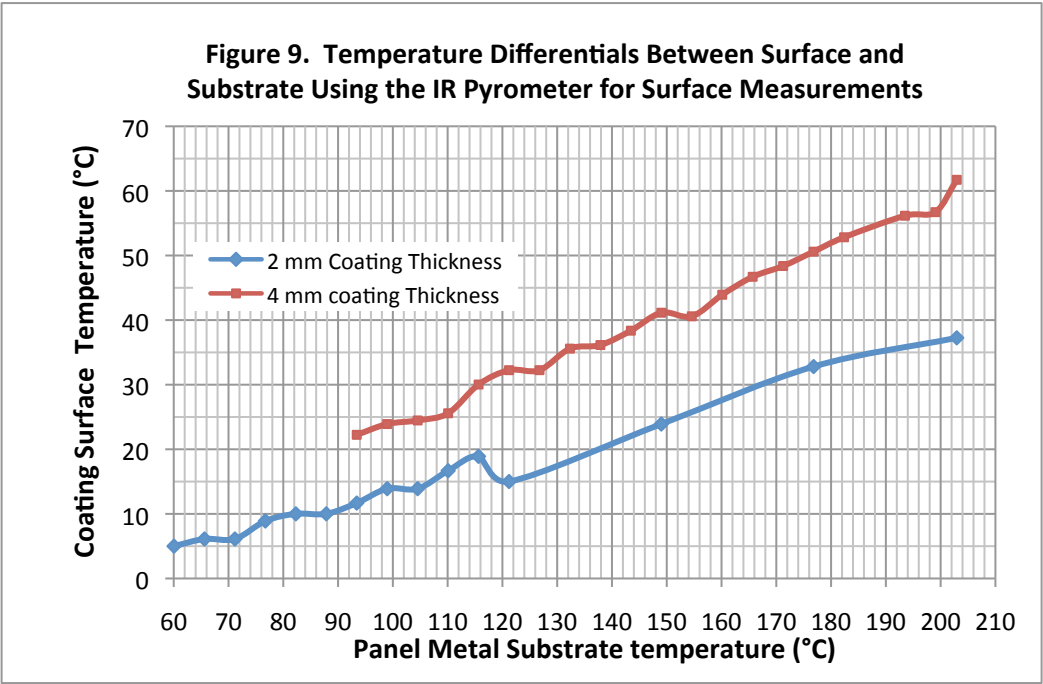
case scenario of 38°C instead of 19°C, then the PP/5s limit would be reached at a lower temperature. So, given these two factors, it is felt that the TM is giving a fairly good estimate of the PP/5s temperature (as judged on the bare steel panel). The main idea here is that there are a number of variables that can affect the data in this test. Users must be aware of these variables when designing their test procedures with the TM to determine maximum temperature limits. Both ASTM and ISO standards emphasize to use worst-case situations and variables when determining these limits.

Because an insulative coating has much lower thermal properties than for metals, the threshold burn temperature will be much higher than for metals. This phenomenon is verified with the TM probe temperatures obtained in the tests reported here. For example, with a 5 second contact time, a carbon steel surface temperature of 69°C (156°F) will conduct the same amount of heat into the TM probe (or into someone's hand) as an insulative coating at a surface temperature of 159°C (318°F). This is like saying that touching an insulative coating surface at 159°C "feels like" touching a carbon steel surface at only 69°C.

Temperature Differentials Between Surface and Substrate

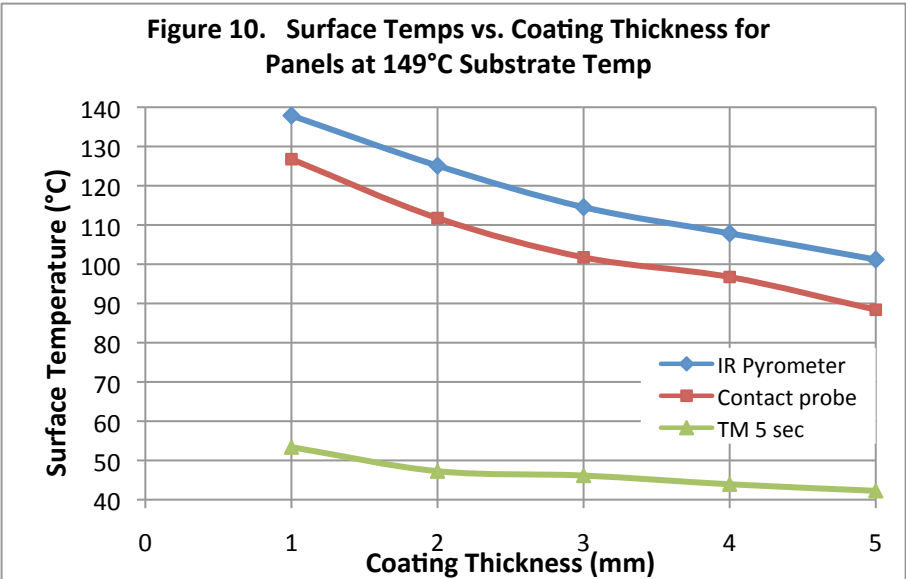
The data from a TM instrument not only helps to determine the temperature limits of a material, but it also provides valuable insight as to how variables can affect the coating performance and its PP/5s temperature limits. Figure 8 gives a graphic comparison of the surface temperatures (from the IR pyrometer) vs. substrate temperatures for the thicknesses from 1-5 mm (40 - 200 mils). As expected, with increasing coating thickness, the surface temperature is decreased for a given substrate temperature. What was unexpected is that the temperature differentials (between surface temperatures for 1 and 5 mm thicknesses) increase with increasing substrate temperature. Comparing 1 mm (40 mil) thickness to 5 mm (200 mils), the surface temperatures of the 5 mm coating decrease 18, 37 and 56°C (32, 66 and 100°F) for substrate temperatures of 93, 149 and 204°C (200, 300 and 400°F) respectively (See Figure 9 for a comparison of differentials for 2 and 4 mm thicknesses.)





Temperature Measurements with IR Pyrometers vs. Contact Probes

Figure 10 gives a graphic comparison of the surface temperatures vs. the coating thickness for a given substrate temperature. The surface temperatures are given for the IR pyrometer, the contact probe and the thermesthesiometer. As expected, with increasing coating thickness, there is a decrease in surface temperature. (Note that the temperature of the contact probe is consistently about 8 to 11°C (15 - 20°F) lower than for the pyrometer). It is felt by the author that the IR pyrometer can give more accurate readings of the coating surface temperature than for the contact probe and readings are obtained in a shorter time. However, the IR pyrometer must have a function to allow entry of emissivity values, and must be calibrated for different materials. In this test, the pyrometer was calibrated with a known surface temperature using an emissivity of 0.97 to match the known surface temperature.

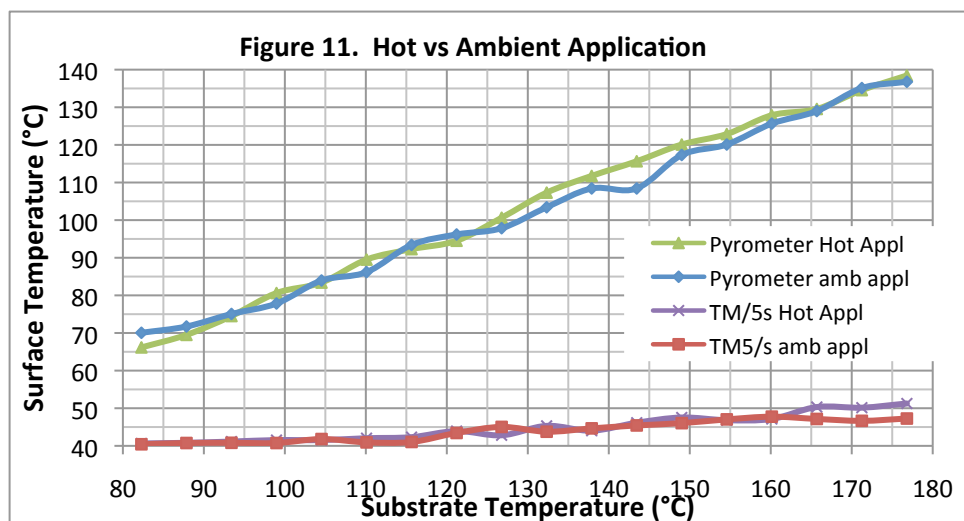


It is also felt that the contact probe measures temperatures fairly accurately for metallic materials that have high thermal conductivities. IR pyrometers do not work well on metallic surfaces. However, the contact probes do not indicate accurate temperatures for materials that have low thermal conductivities. With contact probes on these low thermal conducting surfaces, heat is moved to the ribbon slowly. But heat is also lost as it moves to whatever the material is above the ribbon, be it Teflon or air.

Another issue with the contact probes is that with low thermal conducting materials, they take longer to equilibrate to the temperature of the surface. Users may not be allowing sufficient time for this equilibration resulting in lower surface readings than actual. A third issue with contact probes is that they must be held perpendicular to the surface such that the ribbon is in direct contact with the surface. If held even at a few degrees from perpendicular, one edge of the ribbon will not be touching the surface. A fourth issue is that the ribbons are very delicate and can be damaged such that it will be touching the hot surface on only a small area of the ribbon. For these reasons, the Infra-red pyrometer may be a better instrument for measuring surface temperature for insulative coatings and the contact probe better for metal surfaces.

Comparison of Hot vs Ambient Coating Application

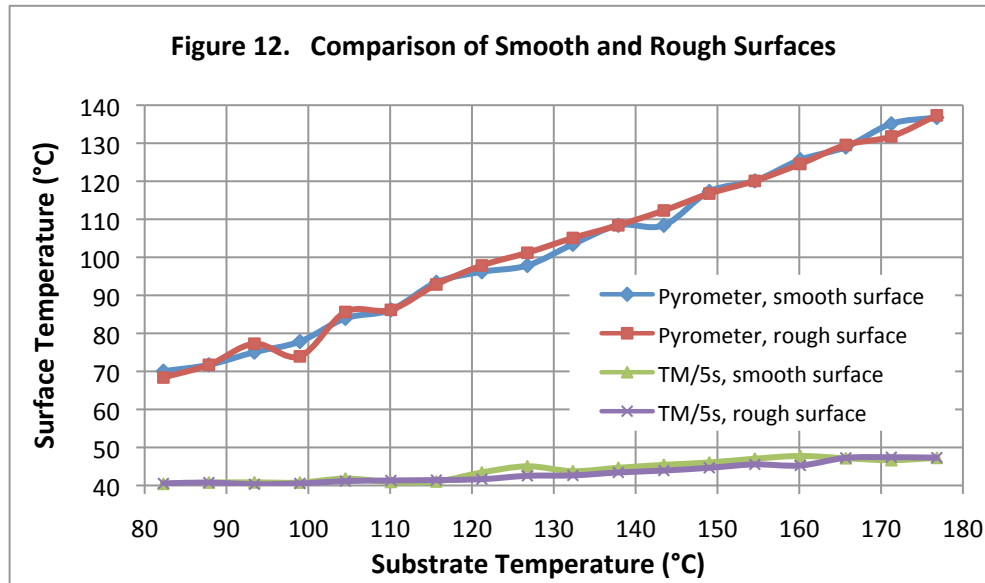
Figure 11 gives a graphic comparison of a coating applied onto a hot surface at 149°C (300°F) to another applied at ambient temperature. The TM data are also included on this graph. Both sets of plots overlap almost exactly. With this comparison, there does not appear to be any significant difference in PP thermal characteristics for a hot applied coating compared to ambient temperature application.



Comparison of Smooth and Rough Surfaces

In this test, two panels were prepared, one with a relatively smooth surface and the other with an intentionally rougher surface. The roughness for the smooth panel was about 7 microns (270 micro-inches or 0.27 mils) and the rough surface was >350 microns (>14 mils). ASTM 1057 recommends a force of 18-22N (4-5 lbs) on the TM probe to get good contact with the surface. The tests were performed with the TM probe being held onto the surface manually by the operator in this range. The TM results are shown in Figure 12 comparing smooth and rough surfaces. On

both sets of graphs, the plots overlap very well and indicate that there is little or no difference in thermal characteristics for smooth vs. rough surfaces. However, it is known that the coating becomes softer with increasing temperatures. It was speculated that the results could have been similar if the peaks on the rough coating were compressed, resulting in a flat surface with more contact with the probe.



Further tests were conducted with a 6 sq cm (1 sq inch) glass panel placed over the rough coating surface with substrate temperatures ranging from 92 to 191°C (200 to 375°F). The glass panel was allowed to rest on the coating surface to obtain the same temperature as the coating surface. At various temperature intervals, a force per unit area similar to that for the TM probe, was applied to the glass panel.

During this compression, the coating surface under the glass was observed (visually) for the degree of compression of the peaks. The results indicated little or no compression between 92 and 121°C (200 and 250°F). There was slight compression at 275-300°F, about 40% compression at 325-350°F and about 50% compression at 375°F. These results clearly show that the rough surface was not completely flattened by the force of the glass or TM probe during the test and compaction of the peaks is not the primary reason for obtaining results similar to the smooth surface. Therefore, in regards to TM testing, it was concluded that rough profiles up to 350 microns does not significantly affect the TM results compared to smooth profiles. This conclusion only applies to the particular coating tested in this report. Other brands of insulative coatings may have different results.

CONCLUSIONS

1. Testing of an insulative coating was performed using a thermesthesiometer in accordance with ASTM C1055, C1057 and ISO 13732-1 to determine the acceptable surface temperature limits for various thicknesses of an insulative coating. This testing verifies that the insulative coating meets the criteria for personnel protection from skin burns.

2. The results indicates that at 38°C (101°F) ambient air temperatures and no wind, a coating thickness of 2.7 mm (109 mils) or greater meets the ASTM C1055 standard up to the temperature limit of the coating.
3. Because of the longer contact time for the PP/5s criteria, it may be considered a slightly more conservative criteria than the PP/4s criteria proposed in ISO 13732-1.
4. Temperature readings of the coating surface with a calibrated pyrometer were consistently higher than for a contact probe. It is felt that the Pyrometer can give more accurate readings of the surface temperature for insulative coatings. However, contact probes are known to be more accurate for measuring temperature on bare metal surfaces.
5. The temperature differential between the substrate metal temperature and the insulative coating surface increases with increasing substrate temperature.
6. There were no significant differences between temperature profiles for hot vs. ambient application temperatures and coatings applied with smooth vs. rough surfaces.

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