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Structural Materials Analyses of the Newhall Pass Tunnel Fire, 2007

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ABSTRACT

On October 12, 2007, a major fire started at approximately 10:40 p.m. in the Newhall Pass tunnel near Santa Clarita, California. The tunnel fire was a result of an accident involving 34 vehicles in and around the Newhall Pass tunnel. One of the vehicles caught on fire and began to ignite the other vehicles in the tunnel. It was reported that smoke appeared to be emanating from the entrance of the tunnel while fire was visible at the exit within 15 minutes of its start. Material samples were recovered from five of the incinerated vehicles. The main objective of the work reported in this report was to examine the collected samples and estimate the temperature reached during the fire. This was determined by evaluating melting points, solid-state transformations, and thermally induced degradation. The materials analysis evaluated many melted aluminum samples, which indicated the temperature reached at least 560°C [1,040°F] at various locations in the tunnel. At other locations, hardness analyses of graded bolts indicated the temperature reached at least 800°C [1,470°F] in one of the vehicles located outside the tunnel. The results of the other bolts for vehicles in the tunnel had reach lower temperature below 750°C [1,380°F]. One brass sample showed incipient melting, which indicated that the temperature at this location reached at least 880°C [1,620°F].

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EXECUTIVE SUMMARY

On October 12, 2007, a major fire occurred in the Newhall Pass tunnel near Santa Clarita, California at approximately 10:40 p.m. The Newhall Pass tunnel is part of the Interstate 5 southbound truck lane, as it passes below Interstate 5 main lanes. The tunnel is a 165.8-m [544-ft]-long reinforced concrete boxed girder, which was built in 1971. The tunnel fire was a result of a truck accident that led to a 34-vehicle pile-up in and around the Newhall Pass tunnel. One of the vehicles caught on fire and ignited the other vehicles in the tunnel. It was reported that smoke appeared to emanate from the entrance of the tunnel, while fire was visible at the exit within 15 minutes of its start.

The main objective of the work reported in this report was to examine the collected samples and estimate the temperature reached during the fire based on material analyses of samples collected from five of the incinerated vehicles. These samples could provide information about the thermal conditions experienced during the tunnel fire. This could be determined by evaluating melting points, solid-state transformations, and thermally induced degradation. The materials analysis examined aluminum, copper, brass, and ferrous alloys. All of the nonferrous samples were analyzed for their melting points. Differential scanning calorimetry was used to measure the melting point of some of the acquired samples. All vehicles sampled showed some signs of incipient melting of aluminum. This indicated the temperature reached at least 560°C [1,040°F] at various locations in the tunnel. At other locations, hardness analyses of graded bolts indicated the temperature reached at least 800°C [1,470°F] for a vehicle outside the tunnel. The other bolts indicated that the temperature was below 750°C [1,380°F] for the vehicles in the tunnel. One brass sample showed incipient melting, which suggests that the temperature at this location reached at least 880°C [1,620°F]. The vehicle from which this sample came was located in the middle of the tunnel, which is where the model predicted the highest gas temperatures.

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: All CNWRA-generated original data contained in this report meet quality assurance requirements described in the Geosciences and Engineering Division Quality Assurance Manual. Data used in this report are primarily derived from other publicly available sources. Each data source is cited in this report and should be consulted for determining the level of quality of those cited data.

ANALYSES AND CODES: No CNWRA computer analysis results are used in this report.

1 INTRODUCTION

1.1 Background

On October 12, 2007, a major fire started at approximately 10:40 p.m. in the Newhall Pass tunnel near Santa Clarita, California. The tunnel fire was the result of a truck exiting the tunnel, losing control, and hitting a concrete median barrier. This led to a chain reaction, and roughly 33 commercial vehicles and 1 passenger vehicle were involved in a multivehicle pile-up, which spanned the full length of the tunnel. Of the 34 vehicles, only 25, including the passenger vehicle, were involved in the fire. The other nine vehicles were only involved in collisions that occurred south of the tunnel exit.

The accident occurred in the Newhall Pass tunnel where Interstate 5 meets Highway 14. The Newhall Pass tunnel is part of the Interstate 5 southbound truck lane as it passes below Interstate 5 main lanes. The tunnel is a reinforced concrete boxed girder, which was built in 1971. An aerial map of Newhall Pass tunnel is shown in Figures 1-1 and 1-2. The fire initiated at the exit (southeast side) of the tunnel and spread throughout the length of the tunnel {roughly 165.8 m [544 ft]}. Figure 1-3 shows the Newhall Pass tunnel exit where the fire began. The winds in this location were reported to be 5.6 kph [3.5 mph] from the south-southwest direction. The tunnel has a 5.5 percent upgrade from the exit to the entrance. Both the wind direction and the tunnel elevation led to a chimney effect, which swept the fire into the tunnel. It was reported that smoke appeared to emanate from the entrance of the tunnel, while fire was visible from the exit within 15 minutes of its start. By 12:00 p.m., October 13, 2007, the fire was completely out on the south portion of the tunnel, but was still smoldering. Flames were still visible at the north end of the tunnel until approximately 6:00 p.m., October 13, 2007. The fire was not fully extinguished until approximately 24 hours after the fire began.

Photographs of the scene during the fire and after the fire was extinguished are shown in Figures 1-4 and 1-5, respectively. California Highway Patrol (CHP)¹ mapped the location of all 25 vehicles before removing them from the tunnel and sending them to various impound lots across the greater Los Angeles area. Most of the commercial vehicles' manifests consisted of produce, which was found along with the remains of the burnt vehicles, as shown in Figure 1-5a. The major remnants of the vehicles consisted of the truck frames, engines, transmissions, axles, and portions of the vehicles that did not melt or burn away in the fire.

The tunnel damage included spalling and cracking of concrete. The fire also heat affected some of the rebar located in the walls of the tunnel (Wiss, Janney, Elstner Associated, Inc., 2007). The abutment walls at the north portion of the undercrossing exhibited more visible damage than the central or south portion. The area where deepest spalling occurred was the northeast walls of the tunnel (entrance). This may have been due to both a lack of firefighting efforts at the entrance and higher temperatures because of the chimney effect. After the fire, the tunnel was repaired in approximately 30 days and reopened to vehicle traffic on November 15, 2007. The tunnel material damaged by the thermal effects of the fire was discarded.

1.2 Objectives and Scope

The main objective of this project was to support the U.S. Nuclear Regulatory Commission (NRC) Division of Spent Fuel Storage and Transportation staff by evaluating the potential

¹California Highway Patrol is referenced throughout the report. The acronym CHP will be used.

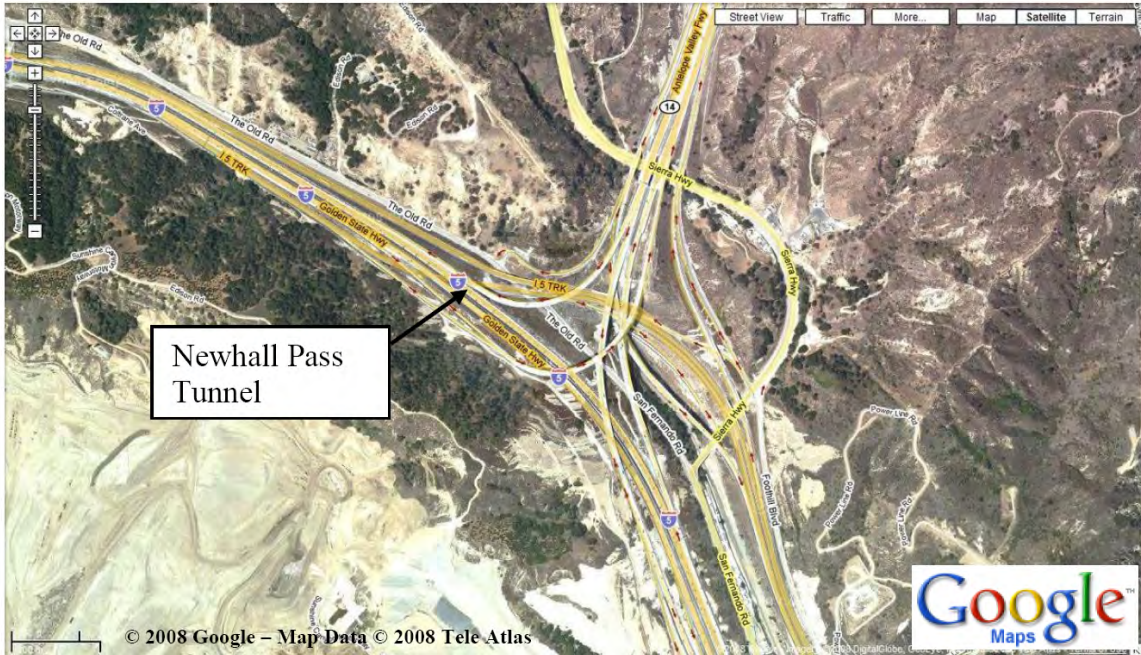


Figure 1-1. Aerial Photograph of Interstate 5 and Highway 14 Interchange



Figure 1-2. Aerial Photograph of Interstate 5 and Highway 14 Interchange. The Accident Initiated on the Exit (Southwest Side) of the Tunnel.



Figure 1-3. Newhall Pass Tunnel Exit After Repair



(a)



(b)

Figure 1-4. Images of Commercial Vehicles on Fire Outside Tunnel Exit. Photos by Gene Blevins/LACOFD/Photo.



(a)



(b)



(c)



(d)

Figure 1-5. Images of Burnt Vehicles After the Fire Had Been Extinguished. Photos Provided by CHP.

performance of structural materials exposed to a high-temperature fire environment. This objective was accomplished by evaluating the thermal conditions that occurred in the Newhall Pass tunnel fire. The temperature profile of the Newhall Pass tunnel fire was evaluated by analyzing materials exposed to the tunnel fire. Melting, solid-state transformation, and thermally induced degradation may provide information on the temperatures experienced during the fire. Three Los Angeles impound lots storing vehicles involved in the fire were visited. Physical samples of aluminum, brass, copper, and graded steel bolts were collected and photographed.

Metallurgical analyses of several material samples from the burnt vehicles were conducted to estimate the temperatures occurring during the fire. Staff could not collect the tunnel material because it had been removed and discarded. The materials analyzed were mainly metallic in nature. Melting point determinations were conducted using differential scanning calorimetry, which can detect melting points with great sensitivity. The melting points can be used to determine a range of temperatures for various locations in the tunnel. In addition to the melting point determinations, bolt hardness was also tested.

2 ANALYSIS OF THE INCINERATED TRUCK SAMPLES

In cooperation with CHP, staff from the Southwest Research Institute[®] accessed the vestiges of five vehicles incinerated in the Newhall Pass tunnel fire and held in vehicle impound lots. The vehicles were visually inspected and supporting photo-documentation was gathered. Samples recovered from the vehicle remnants were used in metallurgical investigations to establish their maximum temperature exposures. The temperature data established bounding temperature values at selected locations in the tunnel fire.

2.1 Description of Samples and Selection of Analytical Approach

During the onsite examination of the impounded vehicles, a variety of materials were acquired including aluminum alloys, copper, brass, and steel. Samples of each type of material were obtained, if possible, from the vehicles that were available. However, some of the vehicles did not contain various materials as shown in Figure 2-2. The metallic samples were specifically selected for their use in quantifying the thermal excursion of the fire incident. Figure 2-1 shows a schematic view of a tunnel section that includes the vehicles accessed in this study. The red circles indicate those specific vehicles and the approximate locations from which samples were acquired. Samples were recovered from Trucks 9, 14, 17, 18, and 27. The other vehicles were not available to obtain samples. Images of the remains from the burnt vehicles accessed in this study are shown in Figure 2-2. Descriptions of the samples recovered from the vehicles are provided in Table 2-1. Figure 2-1 includes temperature ranges determined in this study for thermal excursions corresponding to specimen locations. The temperature range provides bounds for the maximum temperature expected in that location based on the materials analyses. The bounding temperature values were obtained by examining specimens that presented signs of incipient melting (only nonferrous metals) or changes in hardness values (only steel fasteners) due to the fire exposure. The condition of the samples (i.e. melted, partially melted, or unmelted) were likely due to the sample location in the tunnel and the sample configuration on the vehicle. More details are provided in the following sections about melting temperatures and hardness values of the specimens.

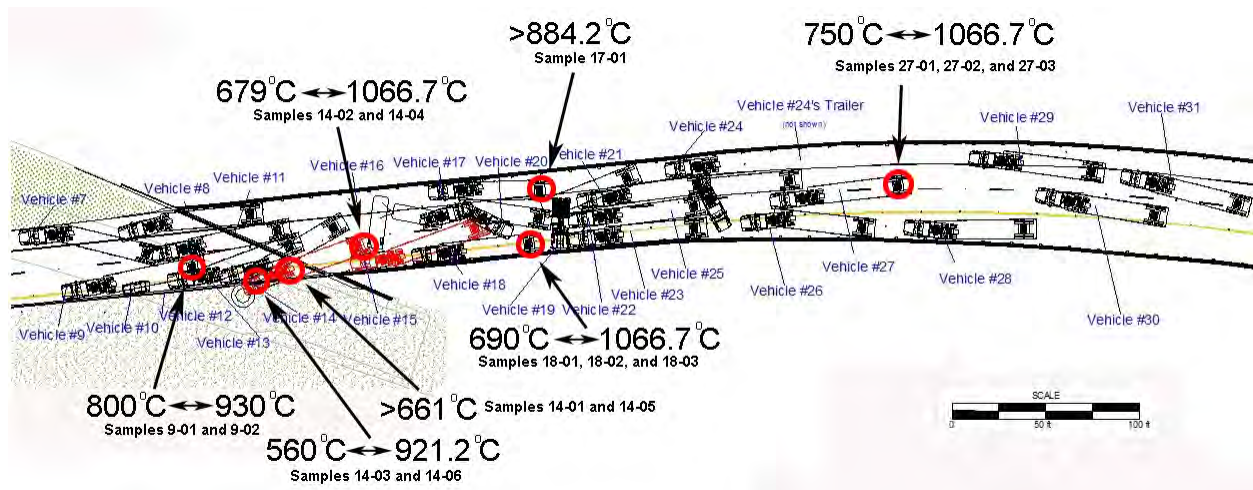


Figure 2-1. Section of Tunnel With Vehicles Accessed for Sample Recovery. The Temperatures Assigned to the Encircled Locations Were Obtained From the Calorimetry Analyses, Visual Inspection, and Mechanical Hardness Measurements. By Analysis of Multiple Substances Obtained From Adjacent Locations, the Exposure Temperatures Were Bracketed. (Image of Vehicle Location in the Tunnel Was Provided by CHP.)

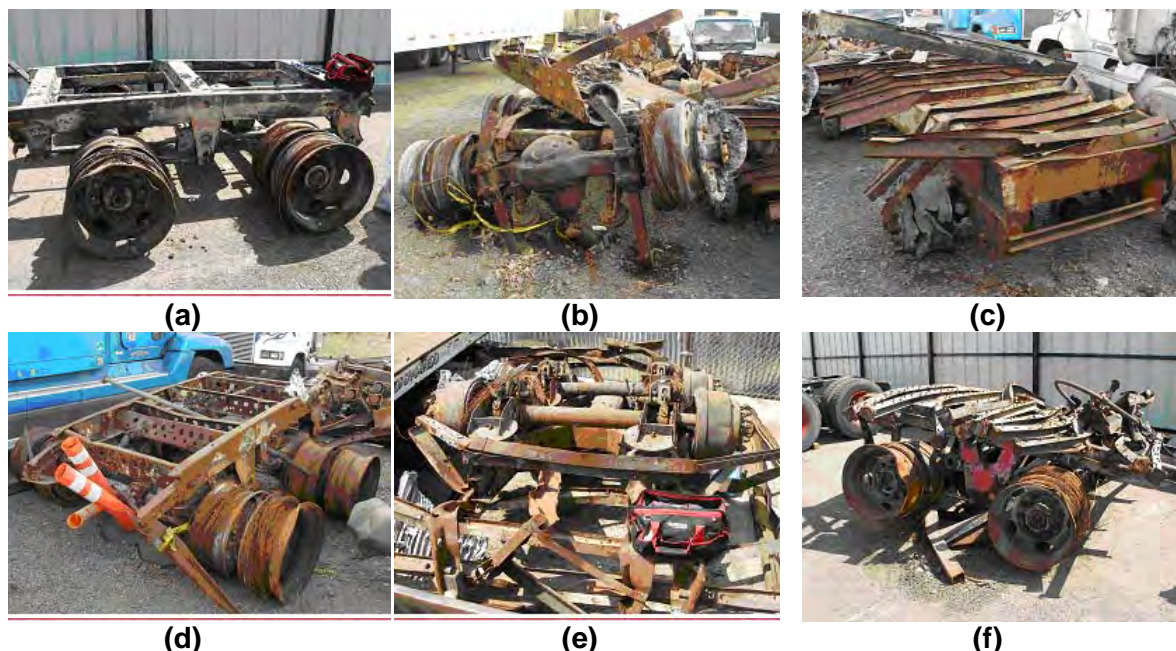


Figure 2-2. Overall View of the Incinerated Vehicles Where Material Samples Were Collected. The Vehicles Examined Included (a) Truck 9 Trailer, (b) Truck 14 Trailer, (c) Truck 14 Trailer, (d) Truck 17 Trailer, (e) Truck 18 Trailer, and (f) Truck 27 Trailer.

Table 2-1. Description of Samples Collected From Incinerated Vehicles	
Sample Identification	Description
Truck Sample 9-01	Melted aluminum and Grade 5 bolt from trailer wheel
Truck Sample 9-02	Brass Schrader valve from trailer wheel
Truck Sample 14-01	Aluminum bracket holding steel cable
Truck Sample 14-02	Copper wire from rear lighting of the trailer with some melted aluminum
Truck Sample 14-03	Brass clamp holding a copper wire from the driver's side engine compartment
Truck Sample 14-04	Melted aluminum and Grade 5 bolt from rear driver's side wheel of trailer
Truck Sample 14-05	Melted aluminum flooring with imbedded steel screw
Truck Sample 14-06	Melted aluminum from the grill of the tractor
Truck Sample 17-01	Partially melted rear brake brass compression fitting
Truck Sample 18-01	Brass clip containing copper electrical wire
Truck Sample 18-02	Melted aluminum and Grade 5 bolt from wheel
Truck Sample 18-03	Melted aluminum and Grade 5 bolt from wheel
Truck Sample 27-01	Melted aluminum and Grade 5 bolt from wheel
Truck Sample 27-02	Melted aluminum from rear of trailer
Truck Sample 27-03	Brass ID tag from axle housing

2.2 Nonferrous Alloy Specimens

A differential scanning calorimeter was used to determine the incipient melting temperature of the nonferrous alloys (i.e., aluminum, copper, and brass) in this study by direct thermal analysis.

The incipient melting temperature is a unique and specific temperature for each substance. The melting temperature will vary with the chemical composition for the alloy. For example, pure aluminum melts at 660°C [1,220°F], but small additions of other chemical elements can both raise and lower the melting point (American Society for Metals, 1990). Similarly, pure copper has a melting point of roughly 1,083°C [1,981°F], but when zinc is added to form brass, the melting point decreases. The first appearance of liquid, at the incipient melting temperature, is the temperature relevant to fire investigations, as it establishes the minimum temperature of the thermal excursion associated with the sample location. The melting temperature for nonferrous specimens described in this report was determined using a differential scanning calorimeter (DSC). This technique provides heat to the sample, while monitoring the temperature. An example DSC thermal analysis trace (Truck Sample 14-02) appears in Figure 2-3. The sudden negative spike indicates the melting temperature of the sample. All of the DSC thermal analysis traces for the specimens examined can be found in Appendix A.

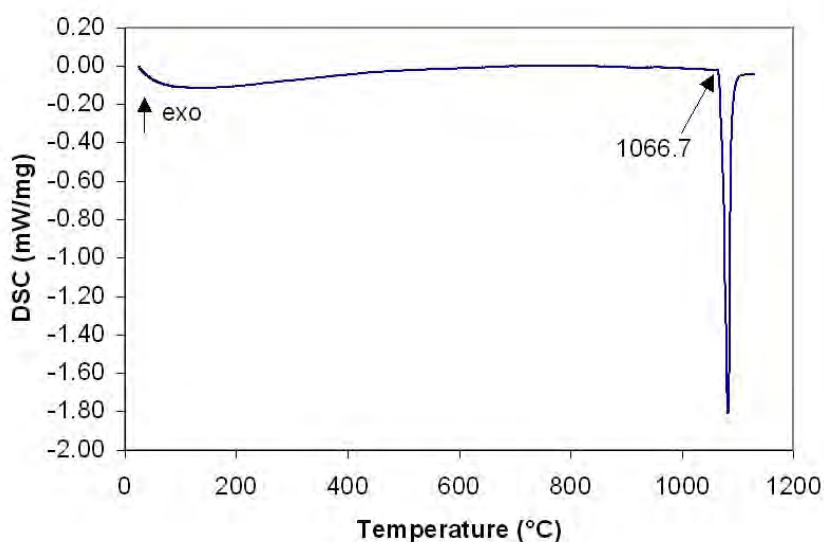


Figure 2-3. Thermal Analysis Trace for a Section of Copper Electrical Wire Removed From One of the Incinerated Vehicles (Truck Sample 14-02). The Curve Indicates the Actual Heat Consumed, and the Inflection Starting at 1,066.7°C [1,952°F] Reveals the Onset of Melting. All Thermal Analysis Data Was Obtained on a Netzsch Model Differential Scanning Calorimeter 404.

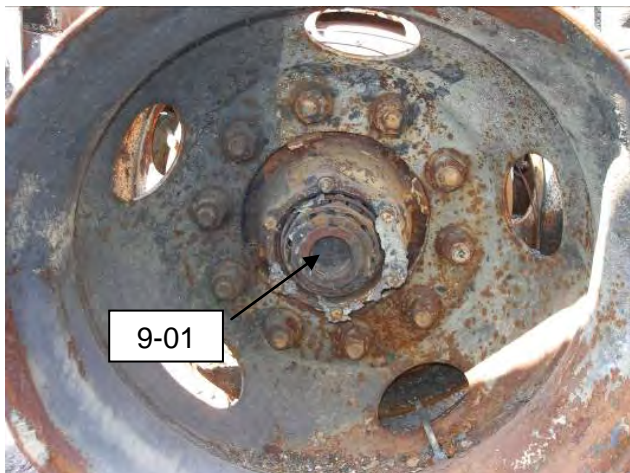
2.2.1 Aluminum Alloys

Aluminum samples collected included parts of wheel rims, tractor grill, trailer flooring, and chassis brackets. While some of the collected samples were fully melted, there were many aluminum components that were only partially melted, as observed in the wheel from vehicle 14 shown in Figure 2-4. The high thermal mass of the alloy wheels requires a commensurately higher thermal load to melt than does the lower mass components of the same composition, such as wire or sheet. Therefore, the part of the wheel that was oriented away from the thermal excursion retained much of its original morphology.

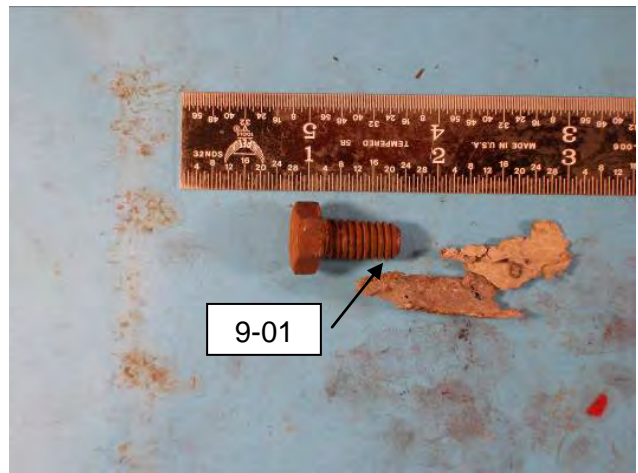
Each of the vehicles discussed previously had at least one sample of melted, partially melted, or unmelted aluminum, as seen in Figures 2-5 through 2-8. Truck Samples 9-01, 14-01, 14-02,



Figure 2-4. The Incinerated Wheel Vestige Shown Here Includes Multiple Metallic Components, Which Were Used To Assess the Fire Severity. This melted aluminum wheel was on vehicle 14.



(a)



(b)

Figure. 2-5. Remnants of a Molten Aluminum Alloy Wheel From Truck 9

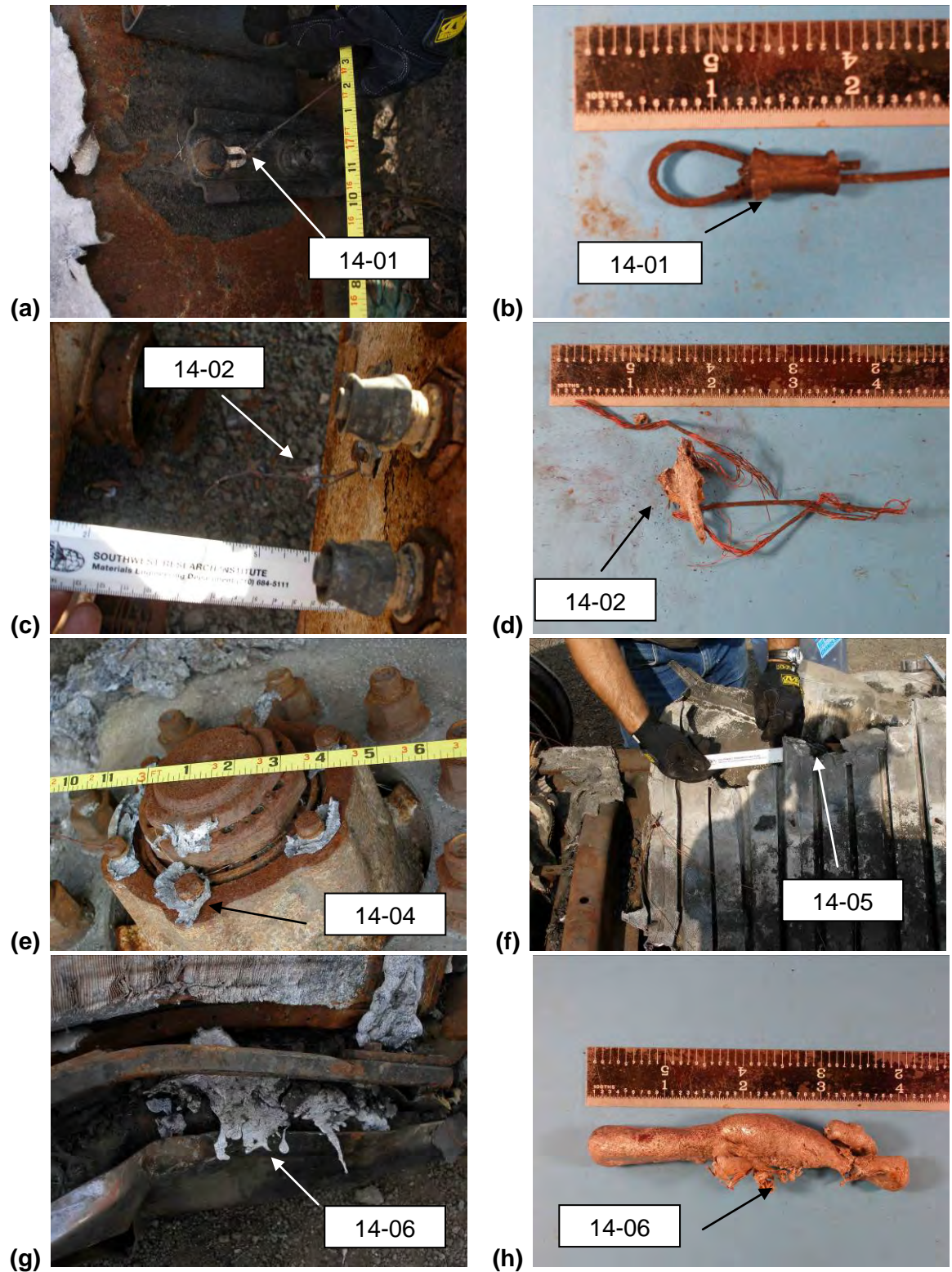
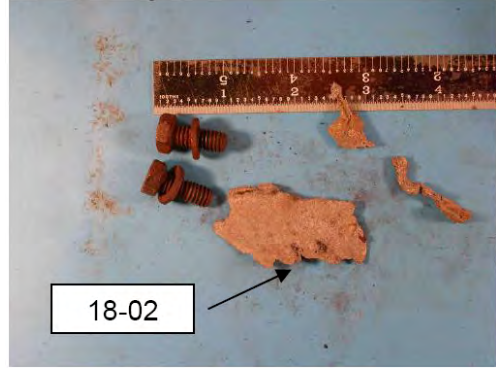


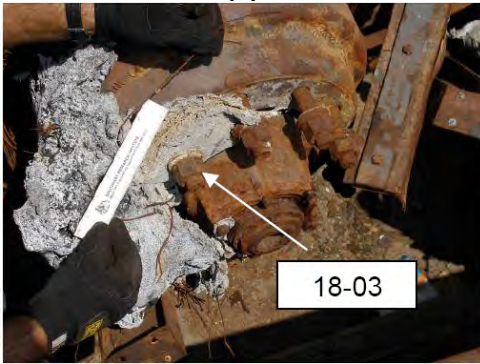
Figure 2-6. Remnants of Aluminum Alloy Wheels and Trailer Flooring From Truck 14



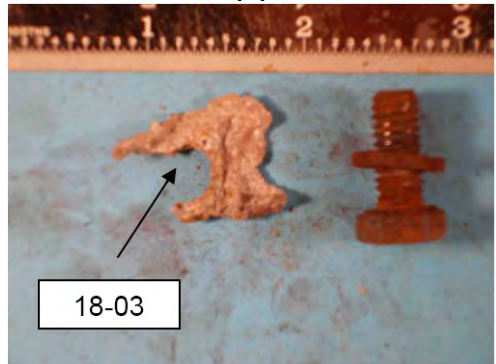
(a)



(b)



(c)

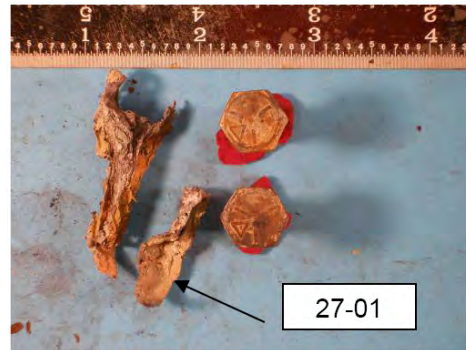


(d)

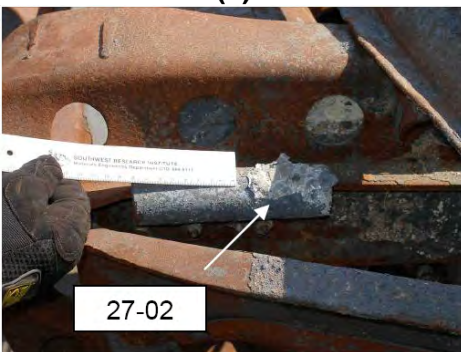
Figure 2-7. Remnants of Molten Aluminum Alloy Wheels From Truck 18



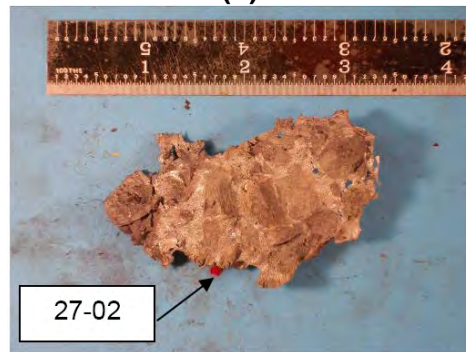
(a)



(b)



(c)



(d)

Figure 2-8. Aluminum Alloy Specimens Showing Clear Indications of Melting and Resolidification Were Recovered From Truck 27

Sample Identification	Melting Point, °C [°F]
9-01	565.0 [1,049.0]
14-01	661.0 [1,221.8]
14-02	679.4 [1,254.9]
14-04	558.1[1,036.6]
14-05	654.3 [1,209.7]
18-02	563.1 [1,045.6]
18-03	571.0 [1,059.8]

14-04, 14-05, 18-02, and 18-03 were analyzed via calorimetry to determine their incipient melting temperatures. The measured solidus temperatures, representing the onset of melting, are shown in Table 2-2. The solidus temperatures vary from approximately 563 to 679 °C [1,045 to 1,254 °F]. The differences are due to compositional variances but are not affected by the presence of any oxide that may have been produced in the fire. For most of the vehicles, aluminum alloys were the only metallic substances that showed signs of incipient melting. The only other metal specimen that liquefied from the fire exposure was a brass fitting on Truck 17, which is discussed in the following section. Hence, the aluminum alloy components established some of the lower bound for temperatures featured in Figure 2-1. Note that although sample 14-01 was composed of an aluminum alloy, it did not show any signs of melting. This sample was recovered from a section where an aluminum alloy part was attached to the vehicle's steel frame. It is unclear why the aluminum alloy did not melt, but is likely due to insufficient heat in that location due to the fire.

In the reactions that proceed in the fire, much of the molten metal reacts with air and the resulting oxide-to-metal ratio indicates the extent of that reaction. As noted previously, the temperature of incipient melting is not influenced by the presence of oxide. However, the calorimetry data are used to provide that oxide-to-metal ratio through the analysis of enthalpy, or heat content data extracted from the thermal traces. The thermal arrests on the traces provide the energy consumed for melting. Taking that data in concert with the known specimen masses, the enthalpy, or latent heat of melting can be obtained. Therefore, with the onset temperature being a fixed quantity for the substance under examination, the higher the energy requirement for the melting reaction, the less metallic content is present. Because the metallic content is inversely related to the oxide content, higher enthalpy values indicate specimens with a greater severity of oxidation in the fire. The calorimetry data indicated that all aluminum alloy samples analyzed were severely oxidized, such that 50 percent or more of the metallic content was absent and the corresponding amount of aluminum oxide was present.

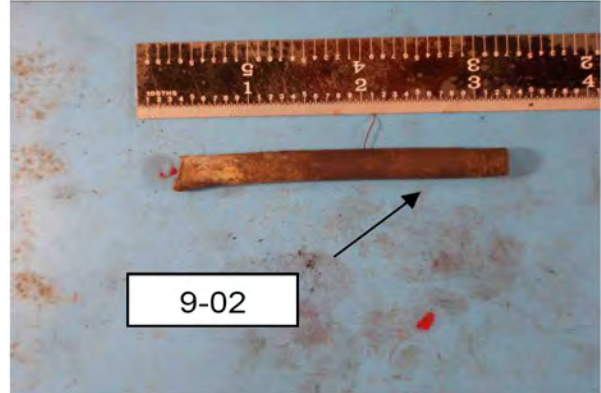
2.2.2 Copper Alloys

Copper wire was found on the vehicles, as it is typically present in automotive electrical systems (ASTM International, 2004). Copper was collected from the battery cable wiring and also brake light fixtures. The smaller gauge brake light wiring would be expected to provide an excellent indication for the surrounding ambient temperature because the low thermal mass responds more rapidly to changes in temperature under applied heat. In addition to copper, there are many brass automotive components representing a range of copper and zinc alloy compositions.

For brass, there is a wide range of compositions with corresponding variations in solidus temperatures. Figures 2-9 through 2-13 show the copper and brass alloys collected from the

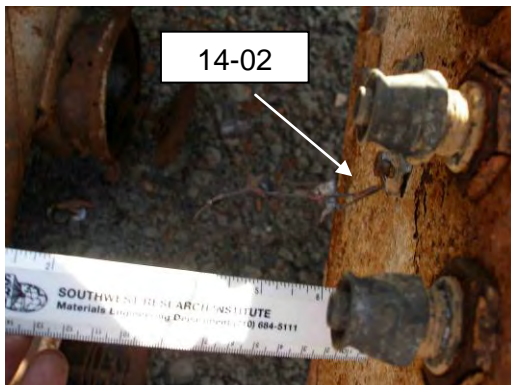


(a)

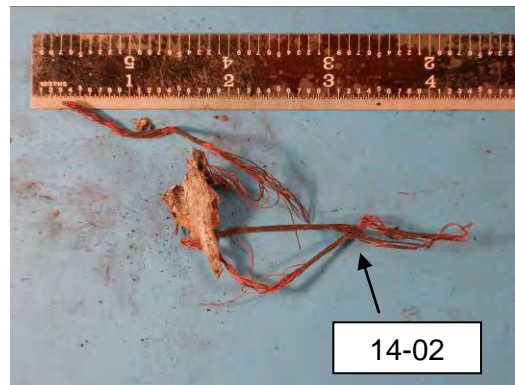


(b)

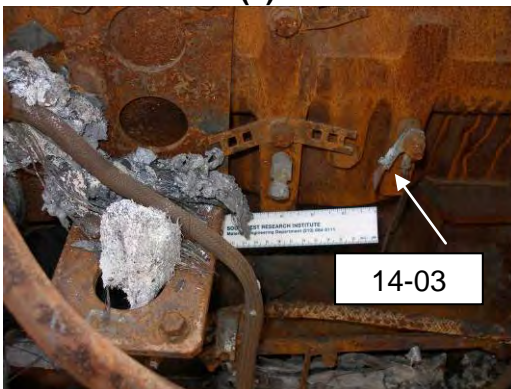
Figure 2-9. Incipient Melting Was Not Present on Copper-Based Samples From Truck 9



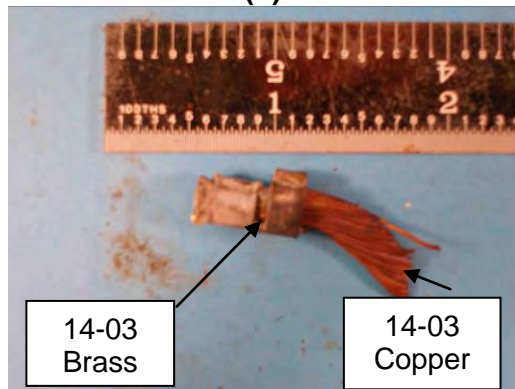
(a)



(b)

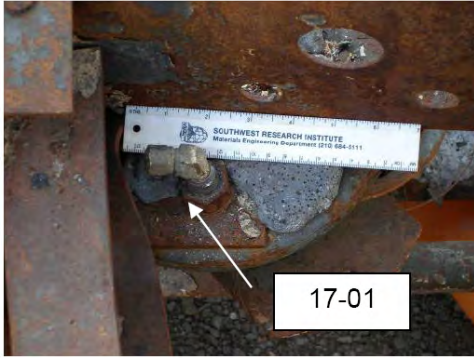


(c)

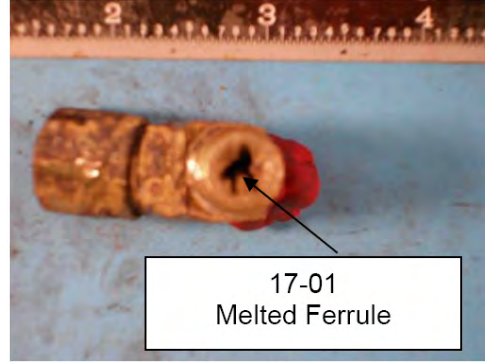


(d)

Figure 2-10. Incipient Melting Was Not Observed on Brass Samples From Truck 14

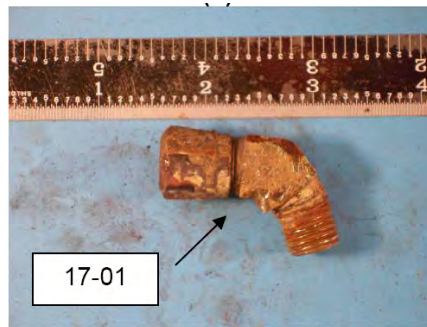


(a)



17-01
Melted Ferrule

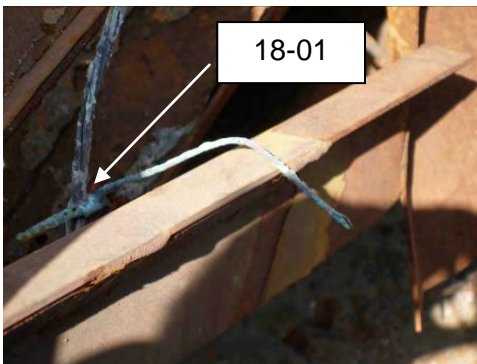
(b)



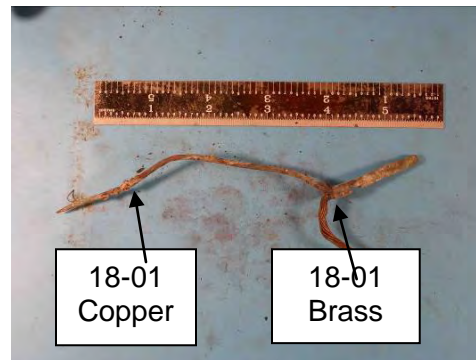
17-01

(c)

Figure 2-11. Incipient Melting of Brass Compression Fitting Ferrule From Truck 17



18-01



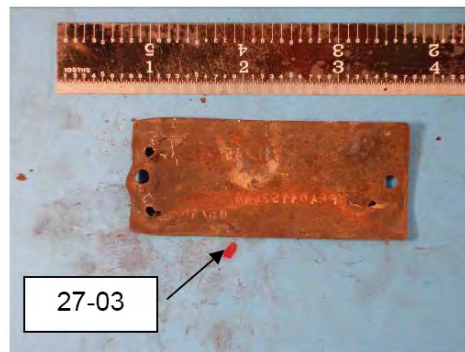
18-01
Copper

18-01
Brass

Figure 2-12. Incipient Melting Was Not Observed on Copper/Brass Samples From Truck 18



27-03



27-03

Figure 2-13. Incipient Melting Was Not Observed on Brass Sample From Truck 27

incinerated vehicles. With one exception, the samples collected showed no signs of incipient melting, which indicates that none of their respective solidus temperatures were achieved in the fire. The single exception was observed with Sample 17-01, where one inside ferrule [shown in Figure 2-11(b)] was observed to have partially melted. Sample 17-01 was collected from the end of vehicle 17 near the brake light area. The opposite side of the fitting had the same internal ferrule, but did not have any indications of incipient melting. The melting temperature determinations by calorimetry indicated that these components had similar incipient melting temperatures, and therefore the difference in melting behavior was likely due to different exposure conditions. The results of these differential scanning calorimeter measurements and other differential scanning calorimeter measurements for copper-based alloys are shown in Table 2-3. As can be seen from Table 2-3, the range of melting temperatures for the sampled brass alloys is between 884 and 1,072 °C [1,623 and 1,961 °F]. The higher melting temperatures correspond to higher copper content. An upper-bound temperature can be set using the melting points for samples that did not show any signs of incipient melting. These upper bounds are indicated in Figure 2-1. The only sample that indicated incipient melting was Sample 17-01, which in the differential scanning calorimeter analysis had an onset of melting at 884°C [1,623°F]. No pure copper was obtained from Truck 17, so it is not possible to establish a bounding temperature maximum below that of the next higher melting constituent, steel.

2.3 Ferrous Alloy Specimens

The ferrous alloy samples remaining from the incinerated vehicles comprised steel and cast iron. Typical samples are shown in Figure 2-14. None of the ferrous alloys had signs of incipient melting. Solidus temperatures for cast iron are in the range of 1,177 to 1,260 °C [2,151 to 2,300 °F] (McIntyre and Ashbaugh, 1996; American Society for Metals, 1978). Carbon steel materials have a melting temperature of approximately 1,516 °C [2,761 °F]. Because there was hardly any melting of brass and no melting of copper observed in the specimen set, it is unlikely that the tunnel fire temperatures were hot enough to melt the ferrous alloys. However, the solid-state transformations in steel, with corresponding changes in hardness, provide a temperature exposure metric, as discussed in Section 4.3.2.

The iron-based components recovered from the vehicle included graded bolts, steel tire cord, steel cables, and steel fittings, which are shown in Figure 2-14. Steel tire cord, shown in Figure 2-14(b), was recovered from an area adjacent to an incinerated trailer wheel. No remnants of the tire remained, and there were vestiges of an aluminum alloy component that had melted and was physically entrained on the steel cord. There was no wetting or reaction between the metals. The nonwetting behavior between the molten aluminum and the steel was due to the iron oxide formed in the fire, which formed a barrier on the steel cord.

Sample Identification	Melting Point, °C [°F]
14-02 copper	1,066.7 [1,952.1]
14-02 copper duplicate	1,072.3 [1,962.1]
14-03 brass	921.2 [1,690.2]
14-03 copper	1,066.8 [1,952.2]
17-01 brass melted	884.2 [1,623.6]
17-01 brass unmelted	929.5 [1,705.1]
18-01 copper	1,064.2 [1,947.6]
18-01 brass	914.2 [1,677.6]



(a)



(b)



(c)

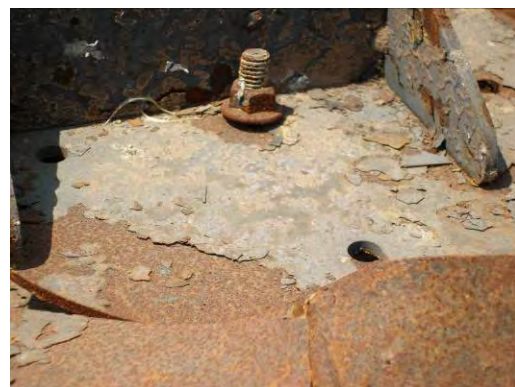


(d)

Figure 2-14. Samples Collected of Steel Alloys Including (a) Graded Bolts, (b) Steel Cables, (c) Steel Cable, and (d) Steel Fittings



(a)



(b)

Figure 2-15. Spalled Oxide From the Carbon Steel Frame

2.3.1 Truck Frames

Severe scaling of steel vehicle frames was observed during the onsite visual inspection. Images of the oxide scaling are shown in Figure 2-15. The presence of oxide scales provides another indicator to establish fire exposure temperature, as scaling temperatures are quantitatively known for various steel compositions. Carbon steel forms oxide scales at approximately 482°C [900°F], while 5Cr-0.5Mo steel produces scales at approximately 621°C [1,150°F] (McIntyre and Ashbaugh, 1996). The steel frame was not analyzed for chemical composition but, consistent with established automotive construction, it would consist of carbon steel. Therefore, the frame sections that exhibited scaling were exposed to a temperature exceeding 482°C [900°F].

2.3.2 Steel Fasteners

Ferrous alloy specimens, in the form of graded bolts, were analyzed by hardness measurements and optical metallography to establish the maximum thermal excursion temperature to which they were subjected. None of the bolts or any other ferrous alloy vehicle components were observed to indicate melting. Hence, the analyses of the bolts focused on microstructural phase changes and the corresponding effect on hardness, as these quantities are influenced by solid-state reactions, which occur at lower temperatures.

The hardness data obtained from the incinerated vehicle samples were compared to the values obtained from a set of reference specimens. The reference specimens that were heat treated and compared to the vehicle bolts were all new, commercially purchased Grade 5 bolts. All of the new bolts had vendor stamps of JH, TY, or arrows (as symbols). The heat treatment and subsequent hardness measurements of the reference specimens were utilized to produce a profile of hardness values as a function of thermal exposure. The hardness values obtained from the vehicles' graded bolts were correlated to the hardness profile of the reference specimens to ascertain approximate fire temperatures at each bolt location.

Compositional analysis was conducted by energy dispersive spectroscopy using a Kevex Sigma system. This analysis was conducted to verify that the alloy content of all the hardware was comparable. The results of this analysis are shown in Table 2-4. The composition of the fasteners affects the hardness and strength. The results from Table 2-4 indicate that Truck Sample 9-01 is most similar to Bolt TY. Truck samples 14-04, 18-02, 18-03, and 27-01 were more similar to the Bolts JH and arrow. Although slight differences are noted in the composition, the hardenability of all the bolts is expected to be comparable.

Sample	Fe	Mn	Cr	Mo	Si	Al
Truck Sample 9-01	99.01	0.76	—	—	0.23	—
Truck Sample 14-04	98.79	0.77	0.14	—	0.31	—
Truck Sample 18-02	98.85	0.72	0.32	—	0.07	0.04
Truck Sample 18-03	98.62	0.90	0.36	—	0.12	—
Truck Sample 27-01	98.63	0.91	0.31	—	0.15	—
Bolt JH	98.52	0.86	0.39	—	0.13	0.09
Bolt TY	99.04	0.82	—	—	0.14	—
Bolt Arrow	98.59	0.81	0.33	—	0.17	0.10

Truck samples 9-01, 14-04, 18-02, 18-03, and 27-01 were collected from the wheels of the various trucks. In addition to the vendor stamping on the bolts, they were also stamped with markings consistent with SAE Grade 5 (SAE International, 1999), which specifies a minimum of 92,000 psi [630 MPa] yield stress; 120,000 psi [830 MPa] minimum tensile stress; and a core Rockwell hardness of C25 to C34 (SAE International, 1999). The bolts were sectioned, and the hardness was measured using a Tukon 2100B hardness tester. Hardness measurements are based on a scale known as the Rockwell hardness scale. There are different scales for different levels of hardness (e.g. Rockwell B and Rockwell C). The hardness measurement is given as a dimensionless number. Although conversion between Rockwell B and C scales reduces accuracy, this approach was necessary to compare values that span a wide range of hardness, such as in the bolts analyzed in this study. The as-collected samples had a core hardness that varied from Rockwell B78 to B101 (approximately Rockwell hardness C0 to C24), as shown in Table 2-5. The hardness for these bolt samples collected from the incinerated vehicles is well below specifications, indicating they had likely been heated well above the minimum tempering temperature, resulting in a reduction in strength and hardness.

The reference specimens that were heat treated and compared to the vehicle bolts were all new Grade 5 bolts. Measurements in the as-received condition, shown in Table 2-6, indicate that they were all within specifications having hardness values between Rockwell C28 and C31 (greater than Rockwell B101). The bolt samples were exposed to temperatures ranging from 400 to 1,000 °C [752 to 1,832 °F] for 2 hours. In addition to these tests, some additional samples were exposed to the temperatures 800 and 1,000 °C [1,472 and 1,832 °F] for either 1 or 4 hours. The process for heating the samples, including preheating the oven to the desired temperature. The samples were then placed in the oven for the directed period of time maintaining the desired temperature. Samples exposed to temperatures above 400°C [752°F] were gradually cooled to 400°C [752°F] prior to removal from the oven and allowed to air cool to room temperature.

The measured hardness value for the heat-treated reference samples is shown in Table 2-6 and presented in Figure 2-16. The effect of temperature on hardness is shown as a decreasing slope. Although there were some slight differences in the chemical composition of the three reference samples, the hardness curves as a function of temperature are very similar. The results suggest that an exposure to a temperature between 800 and 1,000 °C [1,472 and 1,832 °F] for 2 hours would result in a similar reduction of hardness that was observed for the as-collected condition of Truck Sample 9-01. Similarly, the results suggest that an exposure to temperatures of roughly 420, 670, 690, and 750°C [788, 1,238, 1,274, and 1,382°F] would result in a similar reduction of hardness that was observed for the as-collected condition of Truck Samples 14-04, 18-03, 18-02, and 27-01, respectively.

The microstructure for several of the bolt samples are shown in Figures 2-17 and 2-18. All images are reflected light photomicrographs taken in the etched condition to reveal the microstructure. Standard metallographic methods were used to mount, grind, polish, and etch all specimens. The microstructure of the Bolt JH consisted of tempered martensite in the as-received condition, as shown in Figure 2-17a. As can be seen from Figures 2-17b and 2-17c, there is no major change in the microstructure. Not until the heat treatment reached 800°C [1,472°F], was there a change in the microstructure to the spheroidal pearlite structure. This is consistent with the fact that spheroidal pearlite is typically formed in alloy steels at or above 700°C [1,292°F], followed by slow cooling (American Society for Metals, 1978).

Table 2-5. Hardness Measurements for Steel Fasteners Recovered From the Incinerated Trucks	
Sample Identification	Hardness (Rockwell B)
9-01	78
14-04	101
18-02	90
18-03	91
27-01	85

Table 2-6. Hardness Measurements for Reference Steel Fasteners			
Temperature and Heat Treatment Time	Reference Specimen Hardness (Rockwell B)		
	JH	TY	Arrow
As-received	>102*	>102*	>102*
400°C [752°F] for 2 hours	>102*	>102*	>102*
600°C [1,112°F] for 2 hours	96	97	98
800°C [1,472°F] for 1 hour	81	79	82
800°C [1,472°F] for 2 hours	83	81	80
800°C [1,472°F] for 4 hours	84	81	84
1,000°C [1,832°F] for 1 hour	82	78	84
1,000°C [1,832°F] for 2 hours	78	82	82
1,000°C [1,832°F] for 4 hours	74	80	82

*Fastener hardness values were converted to Rockwell B from Rockwell C to compare with recovered fasteners. Although conversion between Rockwell B and C scales reduces accuracy, this approach was necessary to compare values that span a wide range of hardness such as in the bolts analyzed in this study. (ASTM International. "Standard Hardness Conversions Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Knoop Hardness, and Scleroscope Hardness." ASTM E140-07. West Conshohocken, Pennsylvania: ASTM International. 2008.)

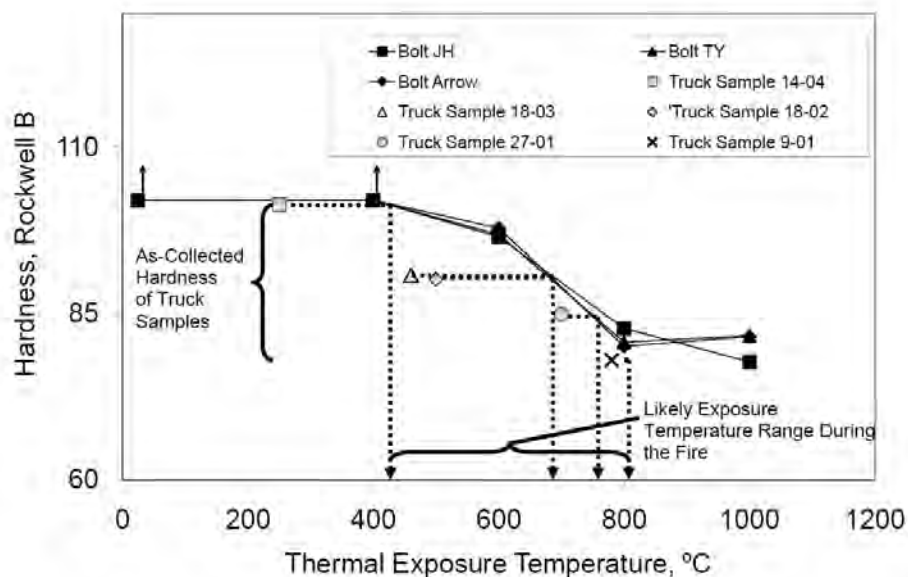


Figure 2-16. Effect of Exposure Temperature on the Hardness of Truck Samples and Commercially Available Grade 5 Bolts

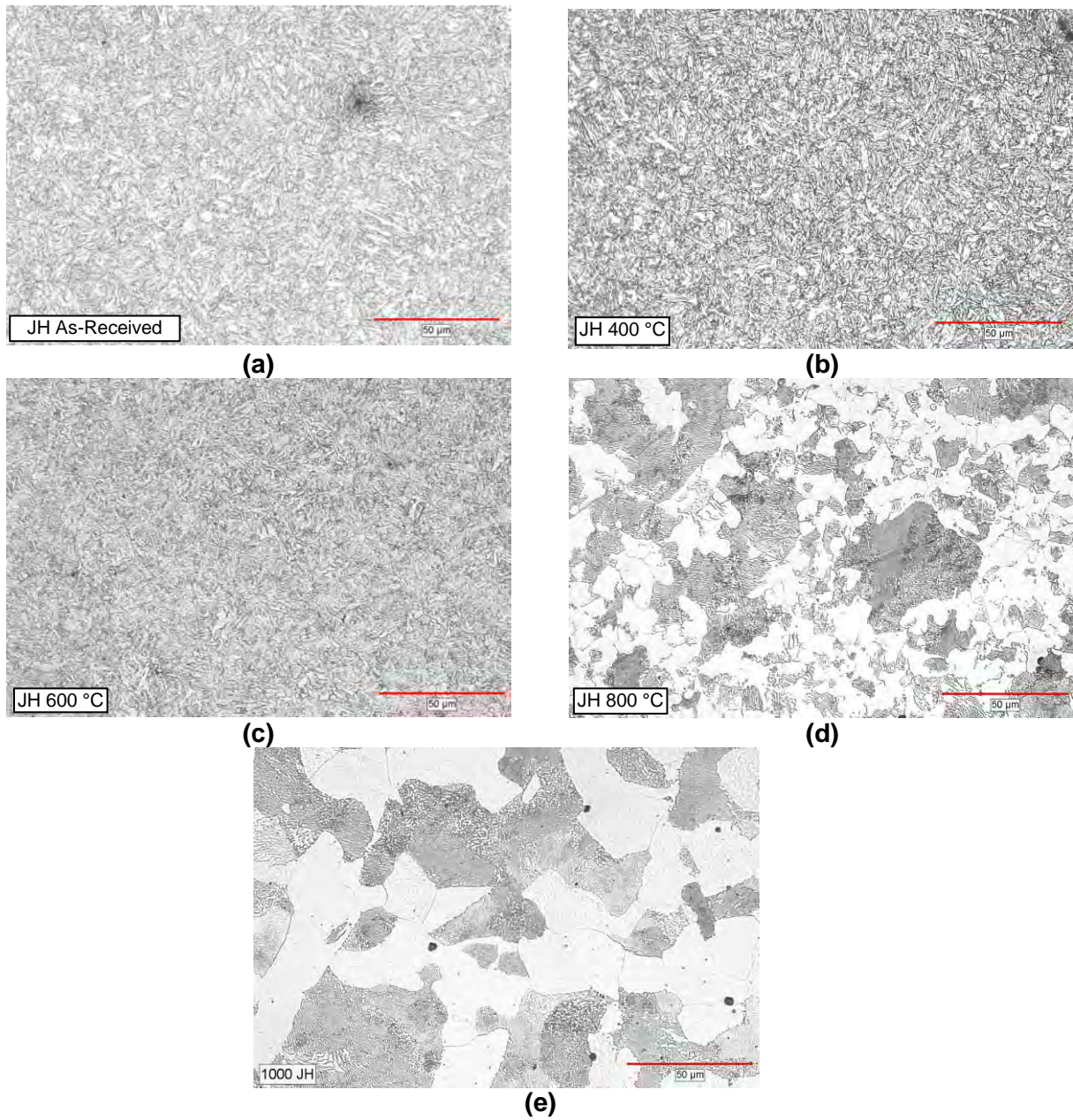


Figure 2-17. Microstructure of (a) As-Received Sample of Bolt JH Showing only Tempered Martensite, (b) Bolt JH After Thermal Exposure at 400°C [752°F] Showing Only Tempered Martensite, (c) Bolt JH After Thermal Exposure at 600°C [1,112°F] Showing only Tempered Martensite, (d) Bolt JH After Thermal Exposure at 800°C [1,472°F] Showing Pearlite, and (e) Bolt JH After Thermal Exposure to 1,000°C [752°F] Showing Pearlite

Figure 2-18 shows the microstructure images of the five evaluated truck samples. As can be seen in Figure 2-18, the only two samples that appeared to form spheroidal pearlite were Truck Samples 9-01 and 27-01.

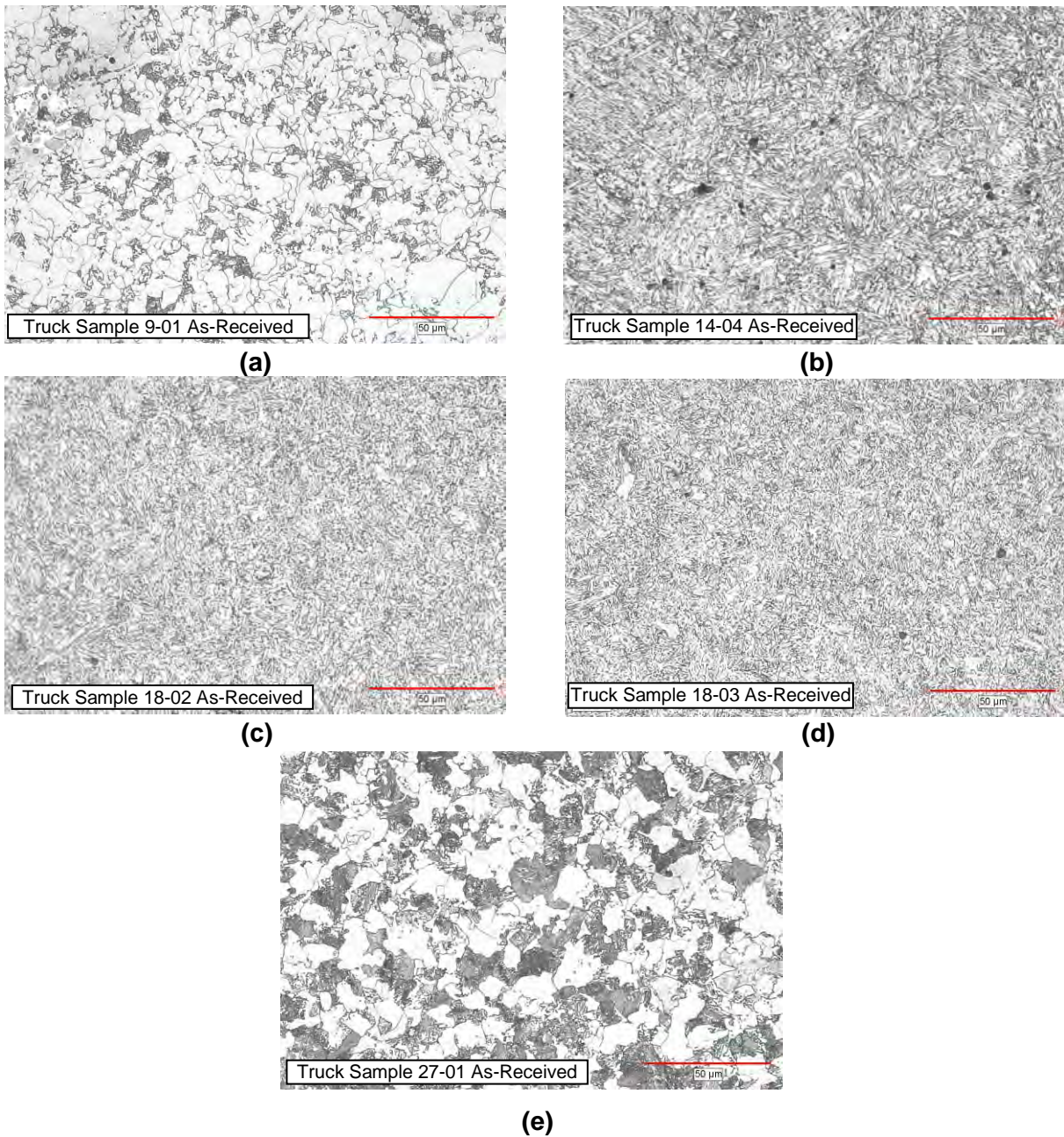


Figure 2-18. Microstructure of (a) Truck Sample 9-01 Showing Pearlite, (b) Truck Sample 14-04 Showing Only Tempered Martensite, (c) Truck Sample 18-02 Showing Only Tempered Martensite, (d) Truck Sample 18-03 Showing Only Tempered Martensite, and (e) Truck Sample 27-01 Showing Pearlite

The microstructure changes of these two samples indicate they were subjected to temperatures over 700°C [1,292°F]. Alternately, Truck Samples 14-04, 18-02, and 18-03 appear to have retained a tempered martensite phase, which suggest these three samples did not reach the

necessary 700°C [1,292°F] for the pearlite transformation. The changes observed in the microstructure data, as a function of temperature, are consistent with the hardness value measurements shown in Figure 2-16.

3 SUMMARY AND CONCLUSION

The objective of this work was to estimate the temperatures observed in the Newhall Pass tunnel during the October 2007 tunnel fire. Temperatures were estimated by collecting and analyzing material samples subjected to the Newhall Pass tunnel fire. Materials were collected from five vehicles including aluminum, copper, brass, and steel components. Melting point determinations were conducted for the nonferrous components. Microstructure and hardness examinations were conducted on the steel fasteners recovered from the incinerated vehicles.

The materials collected from the various vehicles involved in the fire indicate that the temperature in the tunnel reached levels high enough to melt aluminum {i.e., greater than 560°C [1,040°F]}. Melted aluminum was observed from the siding of the trucks to the aluminum wheels. In addition to aluminum alloys, many copper-based alloys, including brass, were collected and analyzed. These materials included copper wiring and brass fittings. Almost all of the copper-based alloys showed no signs of incipient melting. Only Truck 17, where a melted brass ferrule was located, indicated a higher tunnel temperature {i.e., greater than 884°C [1,623°F]} by the melting point analysis. Additionally, hardness data was collected from graded bolts exposed in the fire. The hardness data indicated that the temperature was at least between 400 and 800°C [750 and 1,470°F] at various locations where the fire occurred. It should be noted that the highest temperature from the bolts was from vehicle 9, which occurred outside the tunnel.

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APPENDIX A: DIFFERENTIAL SCANNING CALORIMETRY DATA

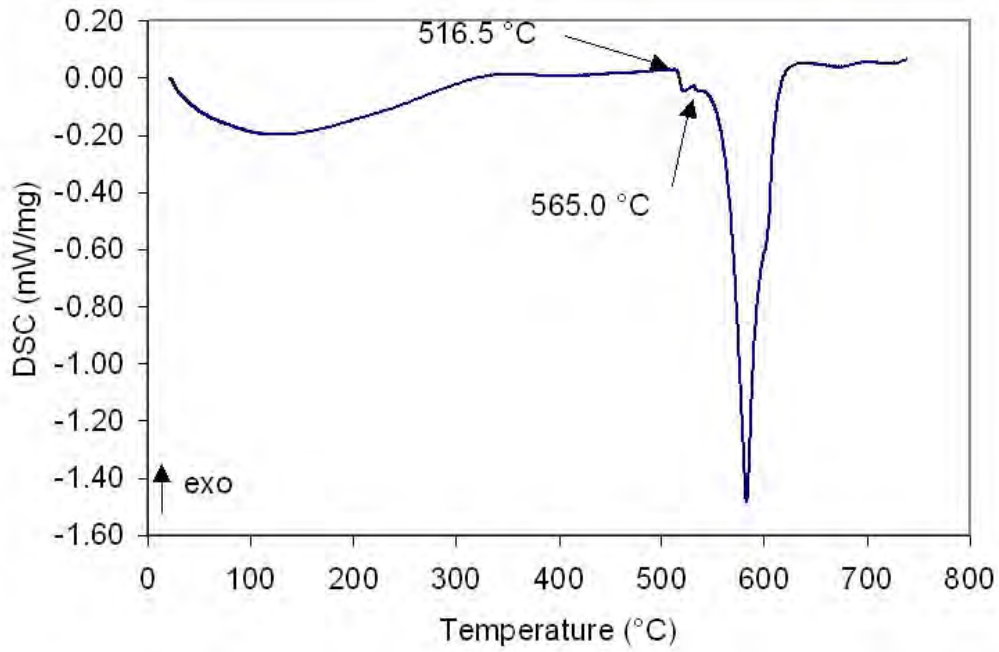


Figure A-1. Differential Scanning Calorimetry Analysis of Aluminum Truck Sample 9-01

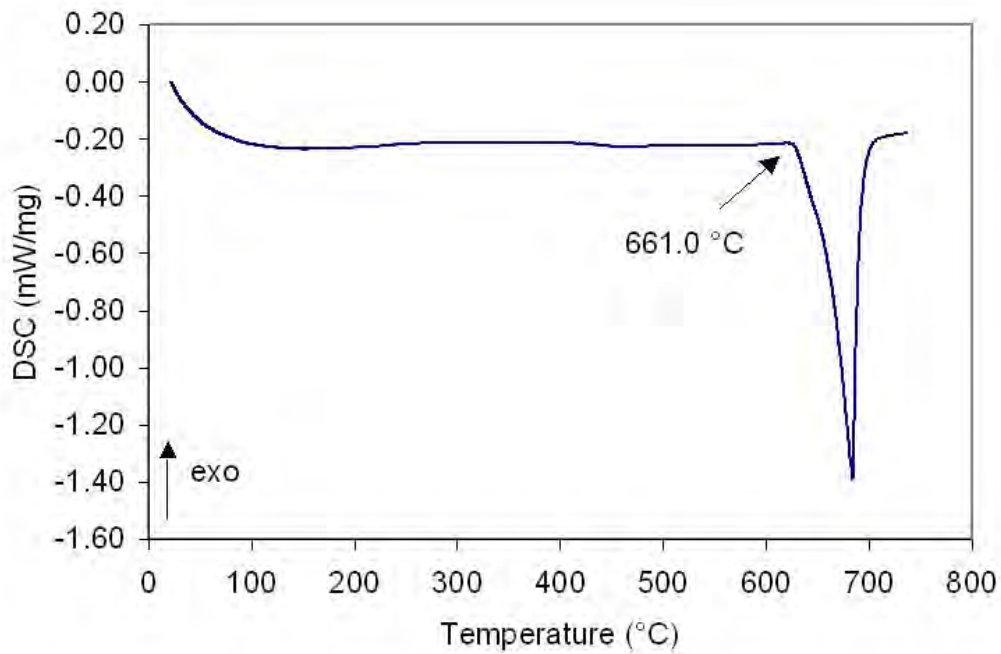


Figure A-2. Differential Scanning Calorimetry Analysis of Aluminum Truck Sample 14-01

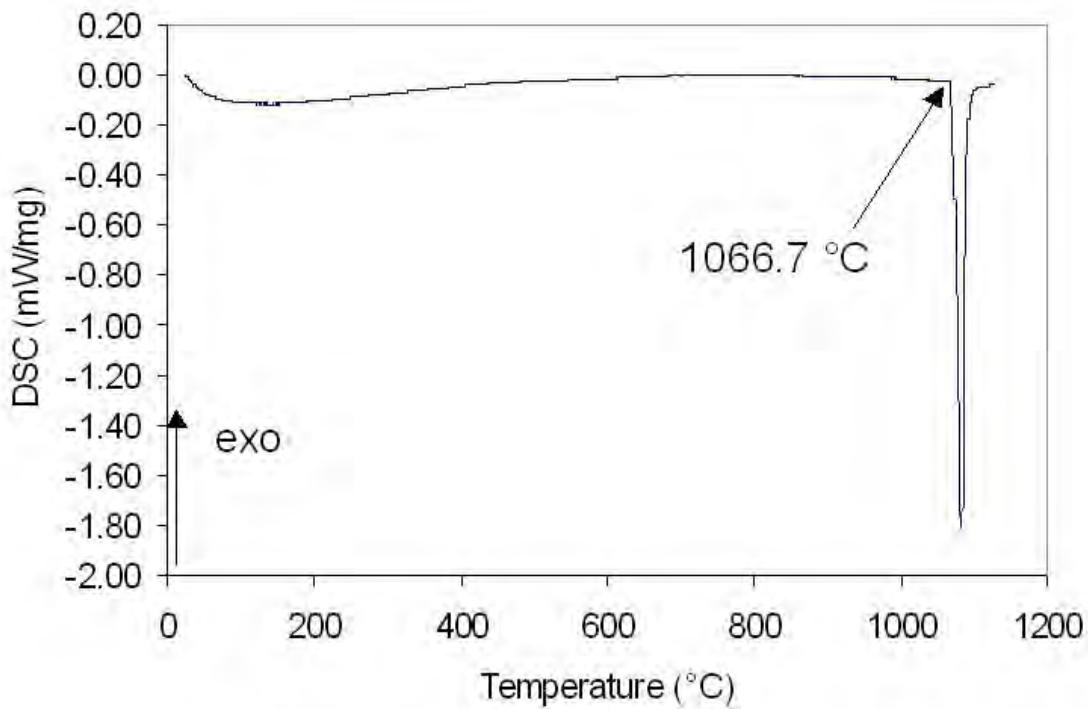


Figure A-3. Differential Scanning Calorimetry Analysis of Copper Truck Sample 14-02

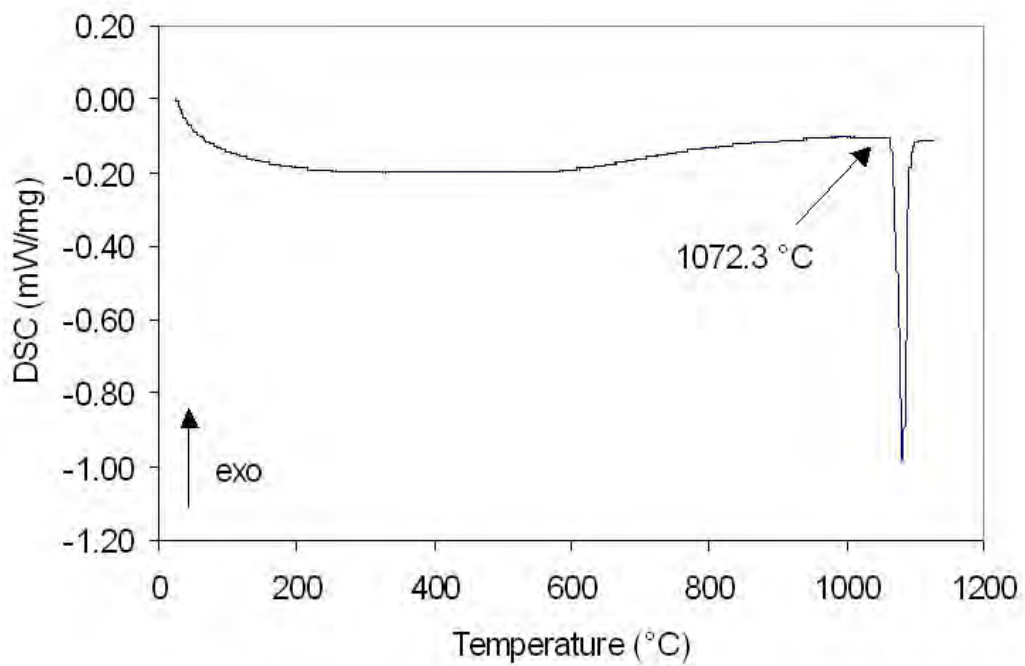


Figure A-4. Duplicate Differential Scanning Calorimetry Analysis of Copper Truck Sample 14-02

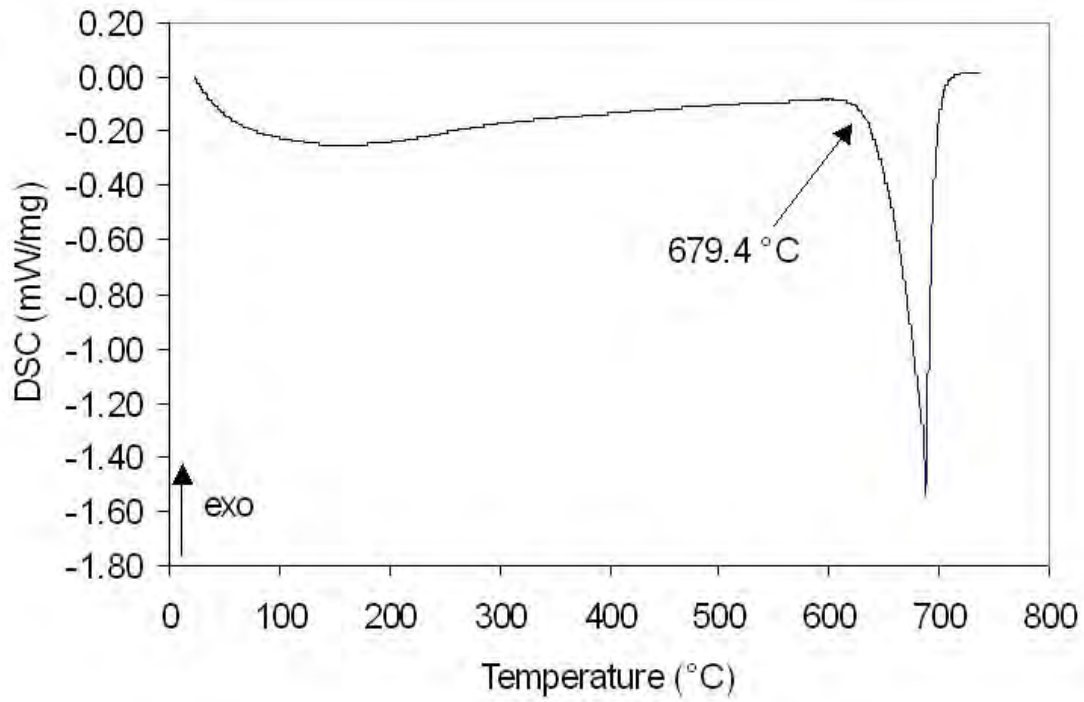


Figure A-5. Differential Scanning Calorimetry Analysis of Aluminum Truck Sample 14-02

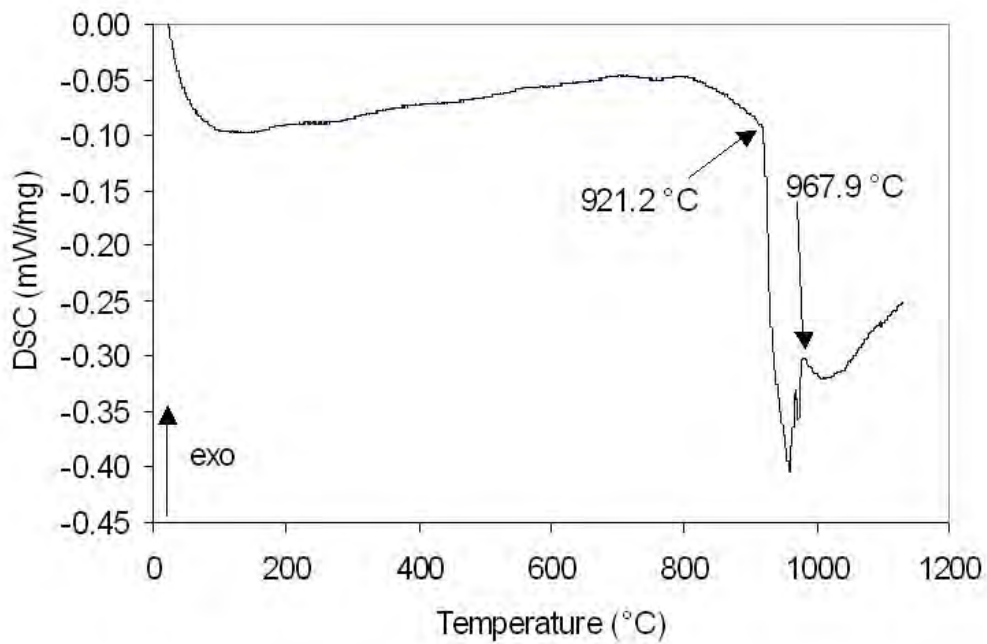


Figure A-6. Differential Scanning Calorimetry Analysis of Brass Truck Sample 14-03

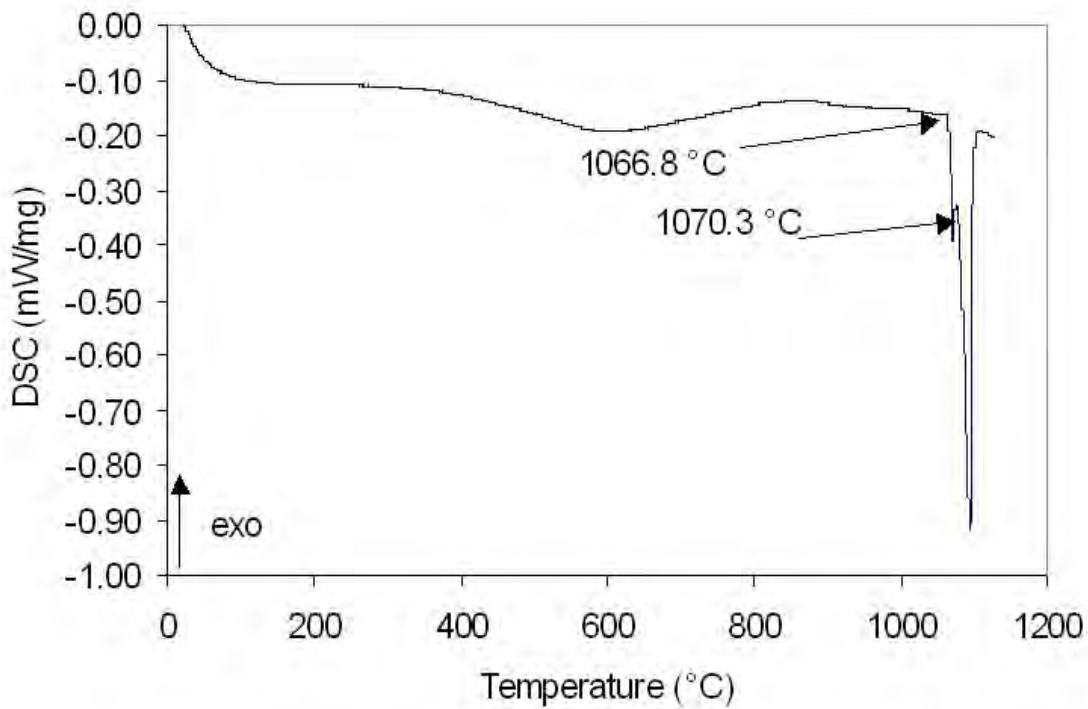


Figure A-7. Differential Scanning Calorimetry Analysis of Copper Truck Sample 14-03

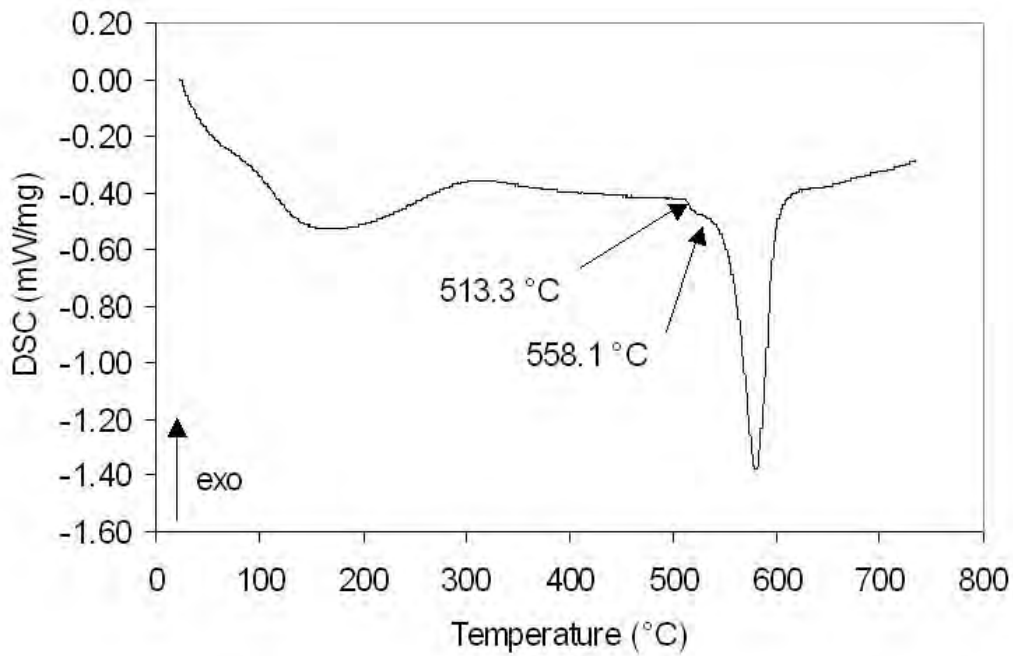


Figure A-8. Differential Scanning Calorimetry Analysis of Aluminum Truck Sample 14-04

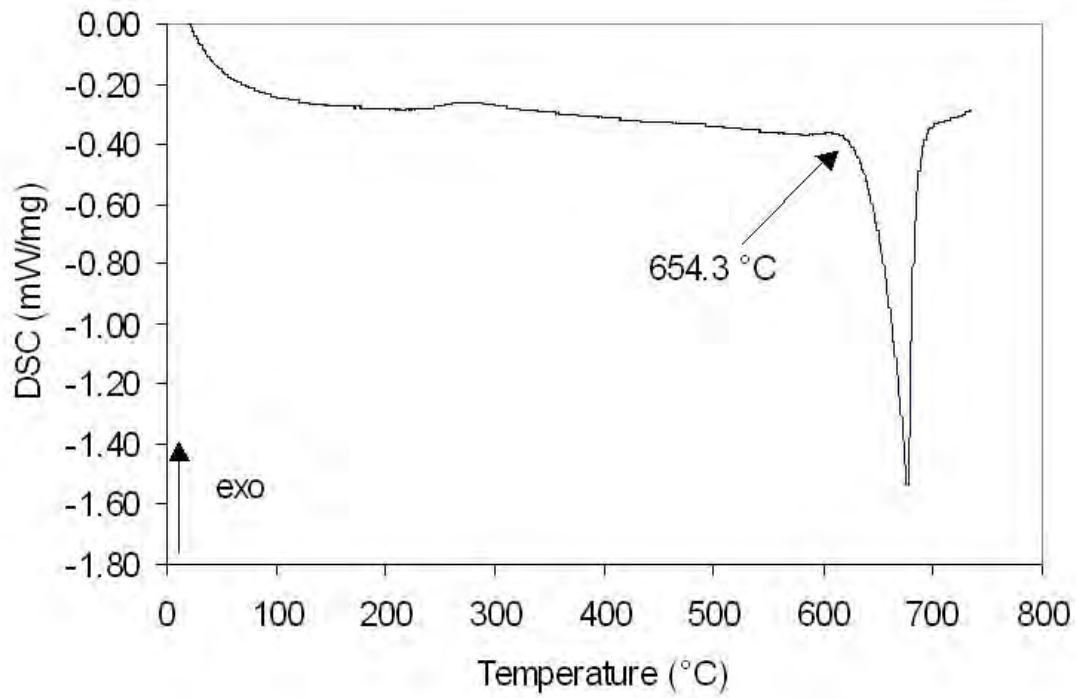


Figure A-9. Differential Scanning Calorimetry Analysis of Aluminum Truck Sample 14-05

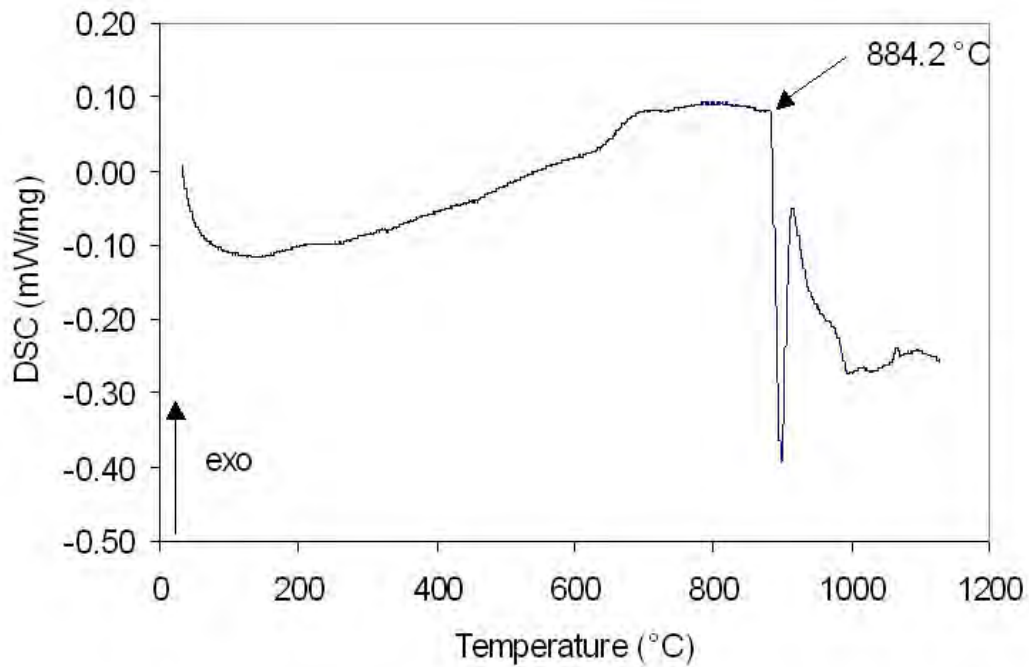


Figure A-10. Differential Scanning Calorimetry Analysis of Melted Brass Truck Sample 17-01

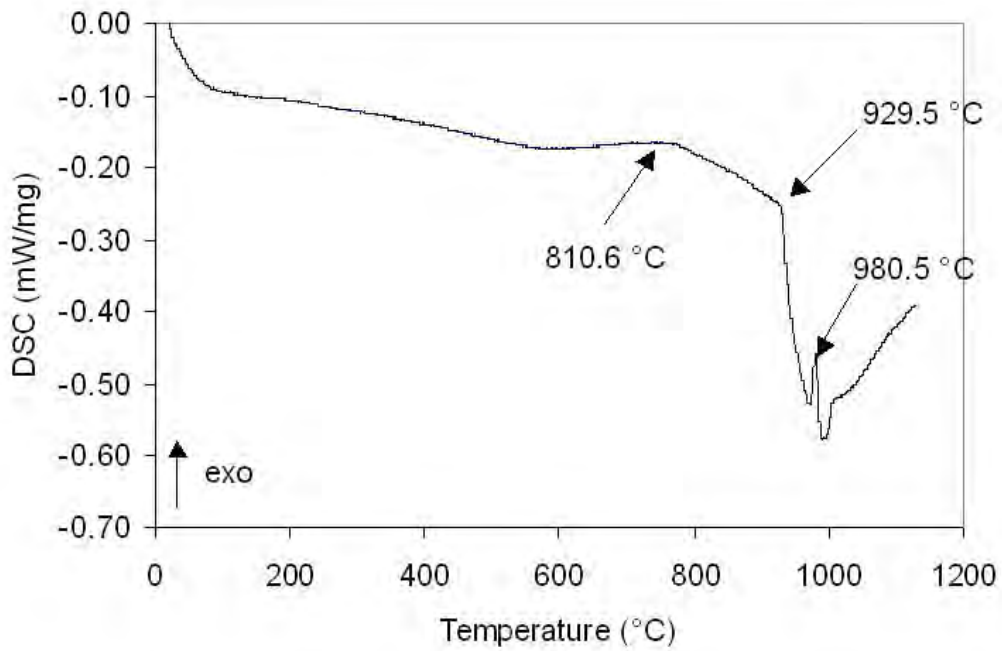


Figure A-11. Differential Scanning Calorimetry Analysis of Unmelted Brass Truck Sample 17-01

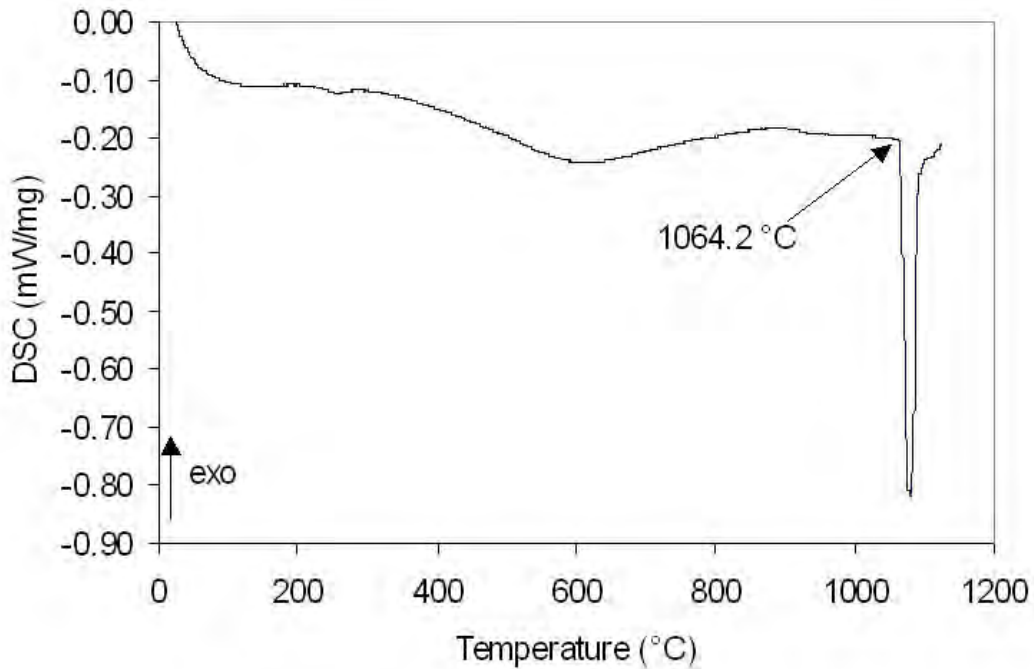


Figure A-12. Differential Scanning Calorimetry Analysis of Copper Truck Sample 18-01

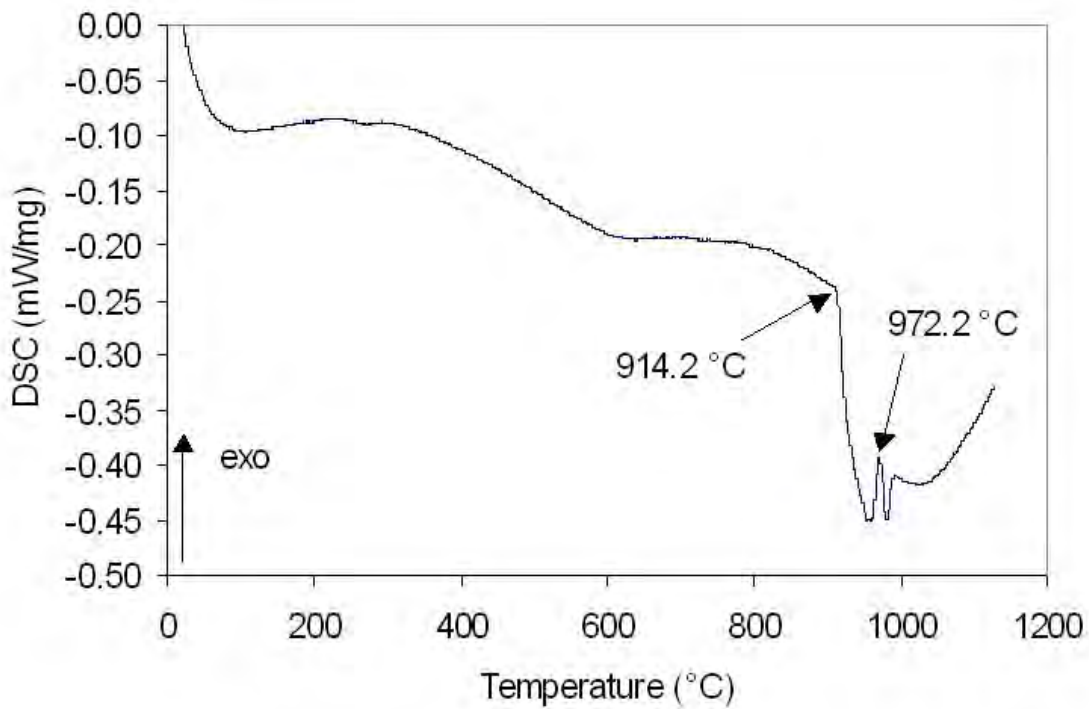


Figure A-13. Differential Scanning Calorimetry Analysis of Brass Truck Sample 18-01

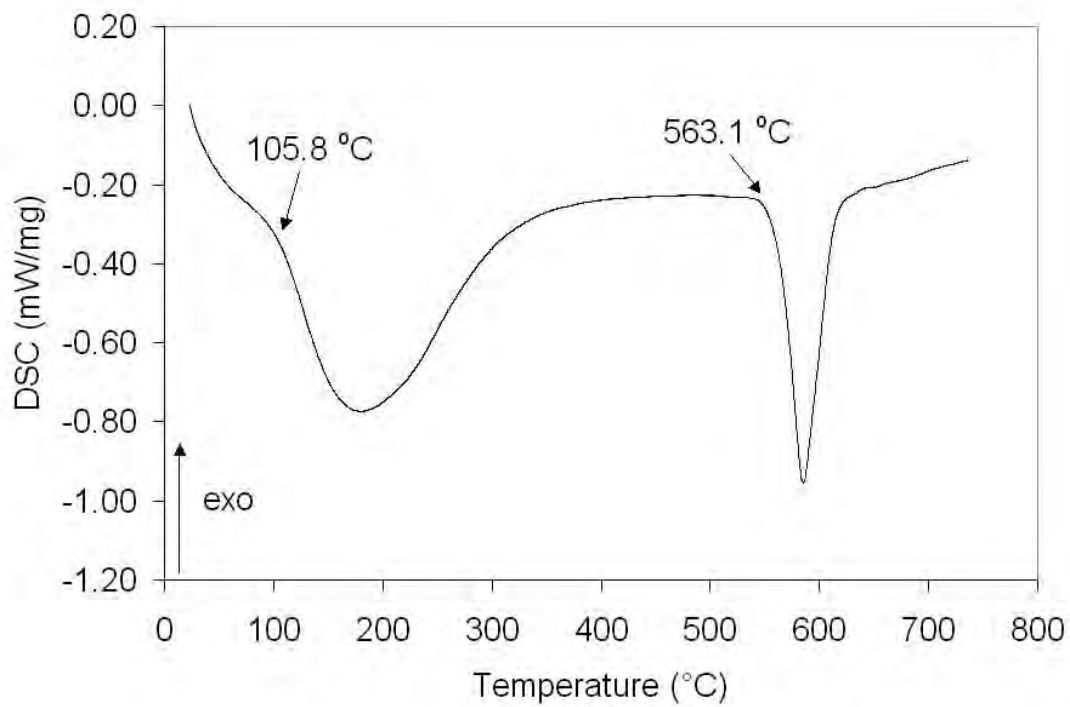


Figure A-14. Differential Scanning Calorimetry Analysis of Aluminum Truck Sample 18-02

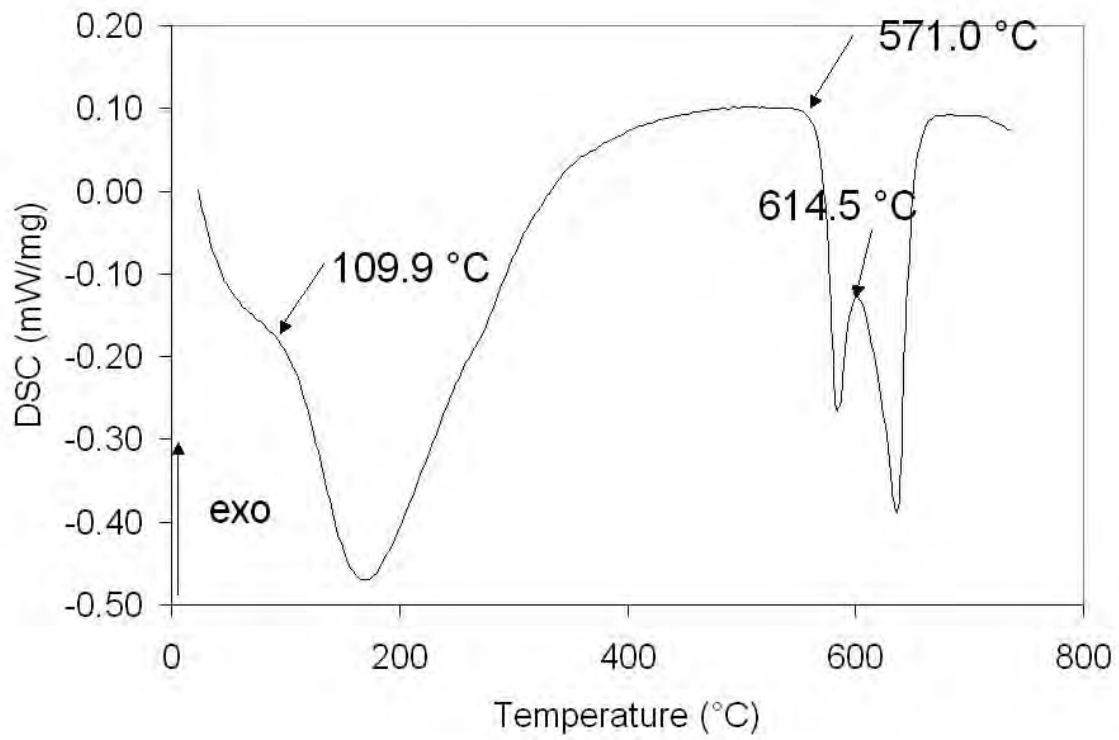


Figure A-15. Differential Scanning Calorimetry Analysis of Aluminum Truck Sample 18-03

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

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10. SUPPLEMENTARY NOTES

C. Bajwa, NRC Project Manager

11. ABSTRACT (200 words or less)

On October 12, 2007, a major fire started at approximately 10:40 p.m. in the Newhall Pass tunnel near Santa Clarita, California. The tunnel fire was a result of an accident involving 34 vehicles in and around the Newhall Pass tunnel. One of the vehicles caught on fire and began to ignite the other vehicles in the tunnel. It was reported that the fire appeared to be emanating from both ends of the tunnel within 15 minutes of its start. Material samples were recovered from five of the incinerated vehicles. The main objective of the work described in this report was to examine the collected samples and estimate the temperatures to which the samples were exposed during the fire. This was determined by evaluating melting points, solid state transformations, and thermally induced degradation. The materials analysis evaluated many melted aluminum samples, which indicated the temperature reached at least 560° C [1,040°F] at various locations in the tunnel. At other locations, hardness analyses of graded bolts indicated the temperature reached at least 750 to 800 °C [1,380 to 1,470 °F]. One brass sample showed incipient melting, which indicated that the temperature at this location reached at least 880°C [1,620°F].

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Newhall Pass
Accident
Fire

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