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Road Tunnels and Fires: Implications for the Transport of Used Nuclear Fuel

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ABSTRACT

In October 2007, just north of Los Angeles, California, a chain-reaction accident involving numerous tractor trailers in the I-5 Newhall Pass truck bypass tunnel occurred. This accident also involved an intense fire that damaged the concrete walls of the tunnel and required the tunnel to be closed for repairs. The objective of the work described in this paper was to determine exposure temperatures in the tunnel and evaluate the conditions likely found in this fire. The study included analyses of materials recovered from the incinerated vehicles and a fire model of the Newhall Pass tunnel fire. While a significant amount of fire modeling has been completed, the results are considered preliminary and, as a result, will not be discussed in detail in this paper. Analysis of a used nuclear fuel transportation package will also eventually be completed as part of this study. This paper will include a discussion of the results of analyses of the materials recovered as well as the potential implications of this accident for the transportation of used nuclear fuel by truck.

NOMENCLATURE

CHP – California Highway Patrol
CNWRA – Center for Nuclear Waste Regulatory Analyses
DSC – Differential Scanning Calorimeter
FDS – Fire Dynamics Simulator
HAC – hypothetical accident condition
NIST – National Institute of Standards and Technology
NRC – United States Nuclear Regulatory Commission
SNF – spent nuclear fuel
SwRI® – Southwest Research Institute®

INTRODUCTION

The NRC is one of the regulatory authorities that oversee the packaging and transportation of radioactive materials. Under current NRC regulations[1], a spent (used) nuclear fuel (SNF) transportation package must be designed to withstand a hypothetical accident condition (HAC) sequence of events, which includes dropping, crushing, puncture, thermal exposure (fire), and immersion in water. The HAC fire is defined as a fully engulfing fire with an average flame temperature of at least 800°C (1,475°F) for a period of 30 minutes. If subjected to a severe fire, the transportation package must maintain containment, shielding, and criticality functions throughout and after the thermal excursion.

The Newhall Pass tunnel fire occurred on October 12, 2007, at approximately 10:40 p.m., near Santa Clarita, California. 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. (See Figures 1 and 2)

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 33 commercial vehicles and 1 passenger vehicle were involved in a multivehicle pileup, which spanned the full 167 m (550 ft) length of the tunnel [See Figure 3(a)]. Twenty-five of the 34 vehicles, including the passenger vehicle, were involved in the fire. The other nine vehicles were only involved in collisions that occurred outside the tunnel. There were three fatalities as a result of the fire.

The Newhall Pass tunnel is a reinforced concrete boxed girder, which was built in 1971. The winds in this location tend to be southerly, which led to the spread of the fire into the tunnel. It was reported that the fire appeared to emanate from both ends of the tunnel within 15 minutes of its start. By 2:47 a.m. on October 13th, the fire was nearly extinguished at the tunnel exit, but still burning within the tunnel. By 4:00 a.m., the fire was essentially extinguished throughout the tunnel, but with smoldering hot spots. At about noon that day, responders began removing damaged and destroyed vehicles from the south end (exit) of the tunnel.

This study of the Newhall Pass fire included an evaluation of the thermal conditions (temperatures and flow of combustion gasses) that occurred both by analyzing

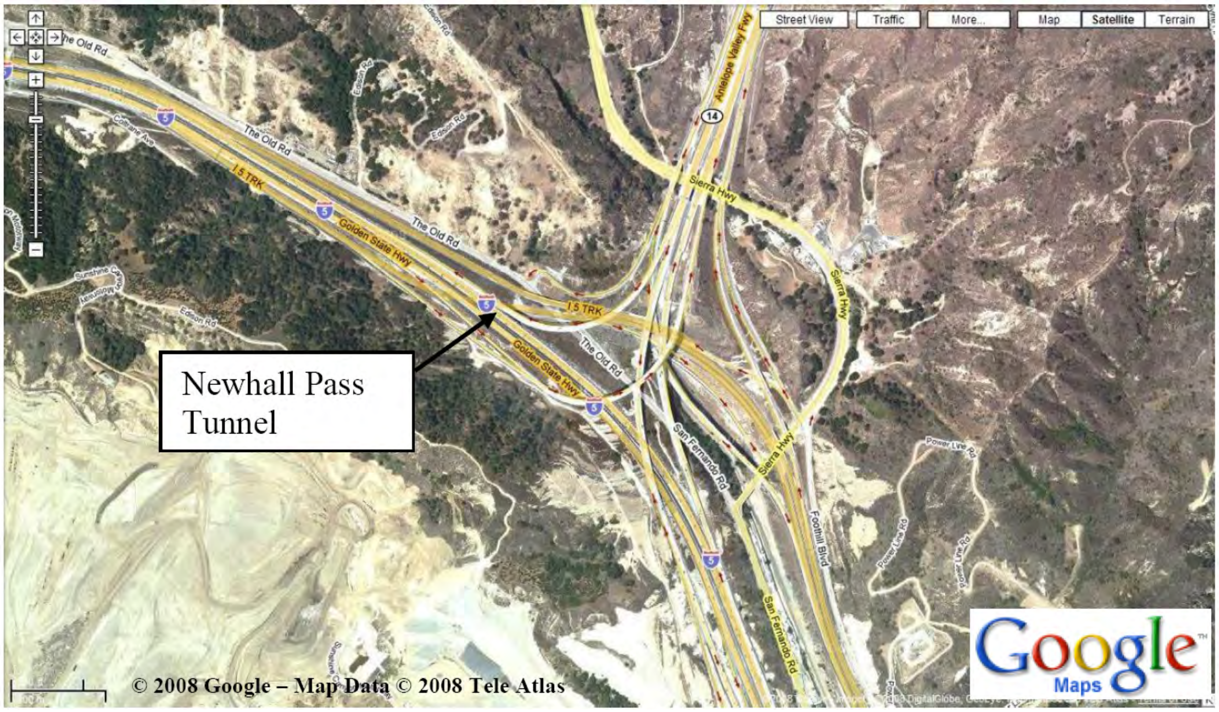
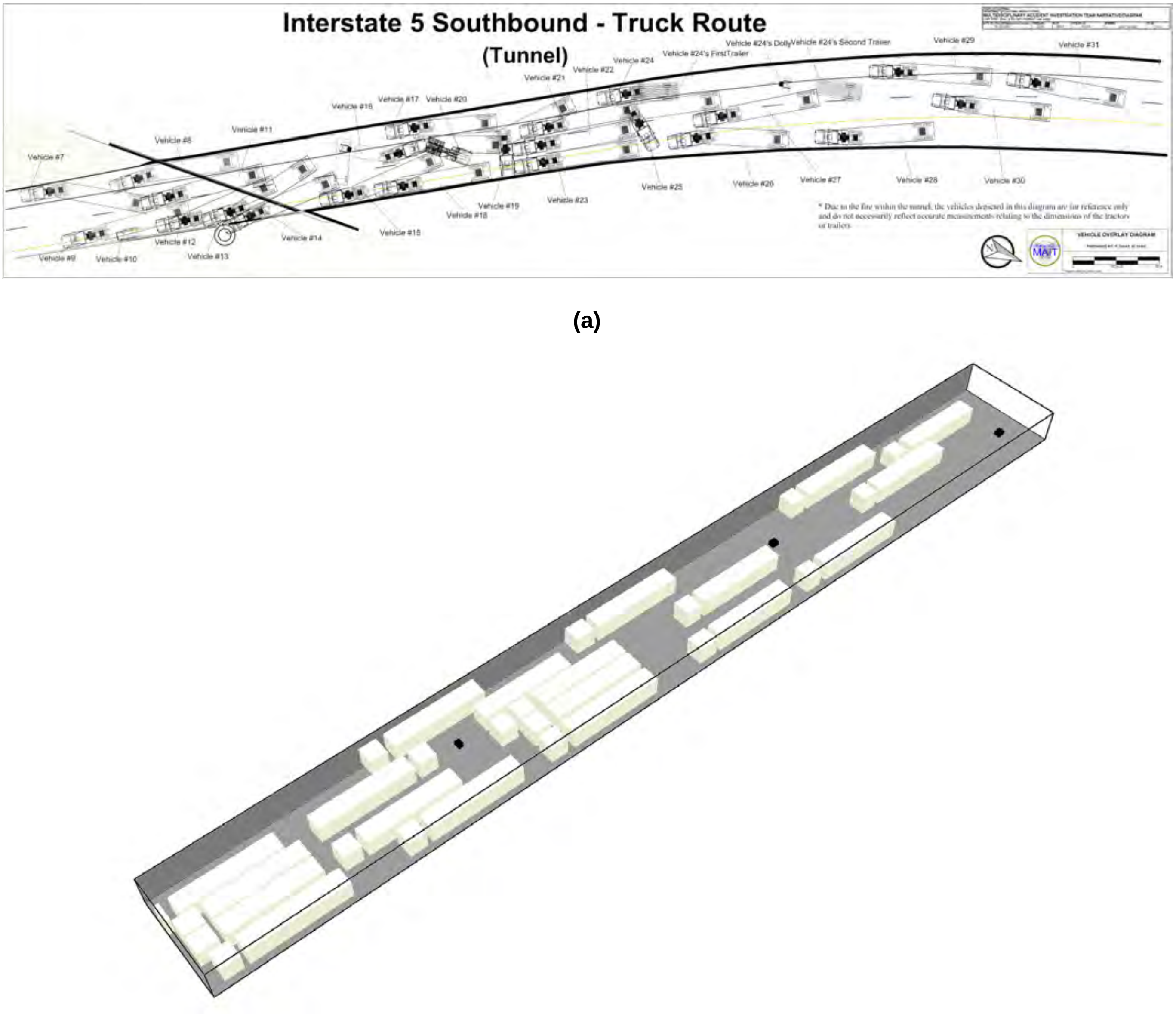


Figure 1. California Interstate 5 and Highway 14 Interchange

Figure 2. Aerial Photograph of Interstate 5 and Highway 14 Interchange

materials exposed to the tunnel fire and by developing a computational model of the fire. Materials analyses were conducted on samples collected from 5 of the 25 vehicles involved in the fire. The objective of the materials analyses work was to evaluate the characteristics of the sampled components exposed to this tunnel fire and estimate an approximate range of temperatures to which these components were exposed. This tunnel fire was also modeled [See Figure 3(b)] using the computational fluid dynamics code FDS (Version 5)[2][3], developed by NIST, to calculate the gas and wall temperatures in the tunnel as the fire progressed. The geometry of the tunnel, amount of combustible materials, and weather conditions were considered in the modeling effort. The information from the materials analyses will be used as a consistency check with the fire model results and to provide additional support for temperature range estimates of the Newhall Pass tunnel fire.



(a)

(b)

Figure 3. Newhall pass tunnel geometry (a) provided by multidisciplinary accident investigation team (courtesy of CHP) and (b) fire dynamics simulator (FDS) model approximation

INCINERATED TRUCK SAMPLE ANALYSES

In cooperation with CHP, staff from SwRI® accessed the vestiges of five vehicles incinerated in the Newhall Pass tunnel fire which were held in vehicle impound lots. (Figure 4) During the onsite examination of the impounded vehicles, a variety of materials were acquired, including aluminum alloys, copper, brass, and steel. The metallic samples were specifically selected for use in quantifying the thermal excursion of the fire incident.

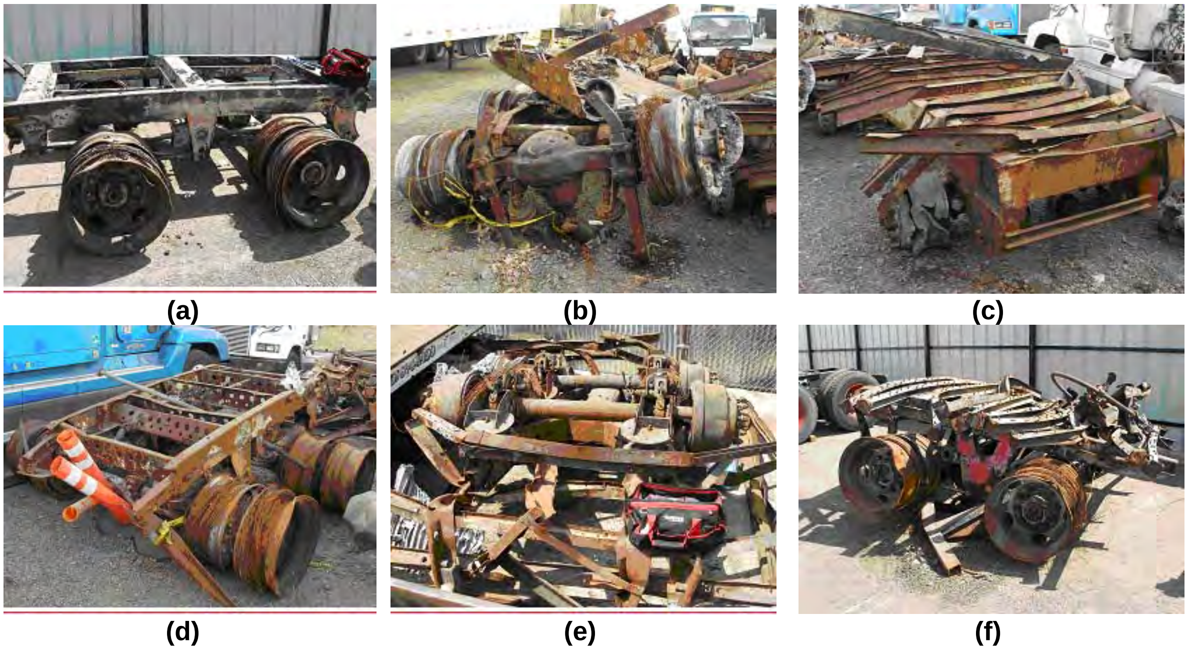


Figure 4. Overall View of the Incinerated Vehicles Where Material Samples Were Collected. The Vehicles Examined Included (a) Truck 9 Trailer, (b) Truck 14 Trailer, (c) Truck 14 Trailer, (d) Truck 17 Trailer, (e) Truck 18 Trailer, and (f) Truck 27 Trailer.

Nonferrous Alloy Specimens

A differential scanning calorimeter (DSC) was used to determine the incipient melting temperature of nonferrous alloy specimens (i.e., aluminum, copper, and brass) in this study. For samples where melting was observed, the DSC measurement provided a lower bound temperature for the material. If no melting of the material was observed, the DSC measurement provided an upper bound temperature known to have *not* been reached by the material. Aluminum was widely sampled, since many truck components are composed of aluminum. The measured solidus temperatures, representing the onset of melting, are shown in Table 1 for aluminum truck samples.

TABLE 1. Melting Point Determinations of Aluminum Samples Recovered From Trucks

Sample Identification	Melting Point, °C (°F)
Truck 9 #1 (melted)	565.0 (1,049.0)
Truck 14 #1	661.0 (1,221.8)
Truck 14 #2 (melted)	679.4 (1,254.9)
Truck 14 #3 (melted)	558.1 (1,036.6)
Truck 14 #4 (melted)	654.3 (1,209.7)
Truck 18 #1 (melted)	563.1 (1,045.6)
Truck 18 #2 (melted)	571.0 (1,059.8)

Copper (wire) is typically present in automotive electrical systems[4], and was collected from the battery cable wiring and brake light fixtures. The smaller gauge brake light wiring was expected to provide an excellent indication of the surrounding ambient temperature because the low thermal mass wire responds rapidly to changes in ambient temperature. In addition to copper, brass is in many automotive components and represents a range of copper and zinc alloy compositions. For brass, there is a wide range of compositions with corresponding variations in solidus temperatures. The brass samples collected, with one exception, showed no signs of incipient melting, which indicates that none of their respective solidus temperatures were achieved in the fire. The single exception was Truck 17 Sample #1, where one inside ferrule of a fitting was observed to have partially melted (Figure 5). The opposite side of the fitting had the same internal ferrule, but did not have any indications of incipient melting. DSC measurements indicated that these components had similar incipient melting temperatures, and therefore the difference in melting behavior was likely due to a thermal gradient. The results of these and other DSC measurements for copper-based alloys are shown in Table 2.

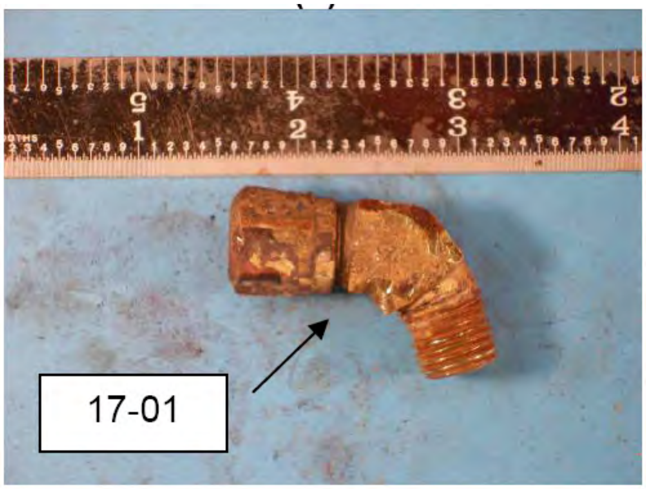


Figure 5. Incipient Melting of Brass Compression Fitting Ferrule From Truck 17

TABLE 2. Melting Point Determinations of Copper-Based Samples Recovered From Trucks

Sample Identification	Melting Point, °C (°F)
Truck 14 #5	1,066.7 (1,952.1)
Truck 14 #6	1,072.3 (1,962.1)
Truck 14 #7	921.2 (1,690.2)
Truck 14 #8	1,066.8 (1,952.2)
Truck 17 #1 (melted)	884.2 (1,623.6)
Truck 17 #2	929.5 (1,705.1)
Truck 18 #3	1,064.2 (1,947.6)
Truck 18 #4	914.2 (1,677.6)

Ferrous Alloy Specimens

The remaining ferrous alloy samples from the incinerated vehicles comprised steel and cast iron. 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).[5][6] Carbon steel materials have a melting temperature of approximately 1,516 °C (2,761 °F). Because there was rarely 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.

Ferrous alloy specimens, in the form of graded bolts, were analyzed by hardness measurements and optical metallography to establish the maximum thermal excursion to which they were subjected. None of the bolts or any other ferrous alloy vehicle components showed indications of 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 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 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). Measurements in the as-received condition, shown in Table 3, indicate that they were all within specifications having hardness values between Rockwell C28 and C31.

TABLE 3. Hardness Measurements for Reference Steel Fasteners

Heat Treatment		**Reference Specimen Hardness (Rockwell B)**		
Temperature °C, (°F)	**Time (hr)**	**JH**	**TY**	**Arrow**
400, (752)	2	> 102*	> 102*	> 102*
600, (1,112)	2	96	97	98
800, (1,472)	1	81	79	82
	2	83	81	80
	4	84	81	84
1,000, (1,832)	1	82	78	84
	2	78	82	82
	4	74	80	82
As-Received Reference Fasteners		> 102*	> 102*	> 102*

*Reference fastener hardness values were converted to Rockwell B from Rockwell C in order to compare with recovered fasteners in Table 4. Although conversion between Rockwell B and C scales reduces accuracy, this approach was necessary to compare values that span a wide range of hardness in the bolts analyzed in this study.[8]

The measured hardness values for the heat-treated reference samples are also shown in Table 3. The sample bolts 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. Samples exposed to temperatures above 400 °C (752 °F) were cooled to 400 °C (752 °F) prior to removal from the oven and allowed to air cool to room temperature.

The hardness values obtained from the evaluation of the graded bolts taken from the vehicles were correlated to the hardness profile of the reference specimens to ascertain approximated fire temperatures at each bolt location. In addition to the vendor stamping on the vehicle bolts, these were also stamped with markings consistent with SAE Grade 5 [7], 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.[7] The bolts were sectioned, and the hardness was measured using a Tukon 2100B hardness tester. The as-collected samples had a core hardness that varied from Rockwell B78 to B101, as shown in Table 4.

TABLE 4. Hardness Measurements for Steel Fasteners Recovered From Incinerated Trucks

Sample Identification	Hardness (Rockwell B)
9-01	78
14-04	101
18-02	90
18-03	91
27-01	85

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, thereby reducing strength and hardness. 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 reduction of hardness similar to that observed for the as-collected condition of Truck Sample 9-01. The results also suggest that an exposure to temperatures of roughly 420, 670, 690, and 750 °C (788, 1,238, 1,274, and 1,382 °F, respectively) would similarly reduce hardness that was observed for the as-collected condition of Truck Samples 14-04, 18-03, 18-02, and 27-01, respectively.

The effect of temperature on hardness is shown in Figure 6 as a decreasing slope in this figure. 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. Hardness values of the graded bolts taken from the vehicles are also shown.

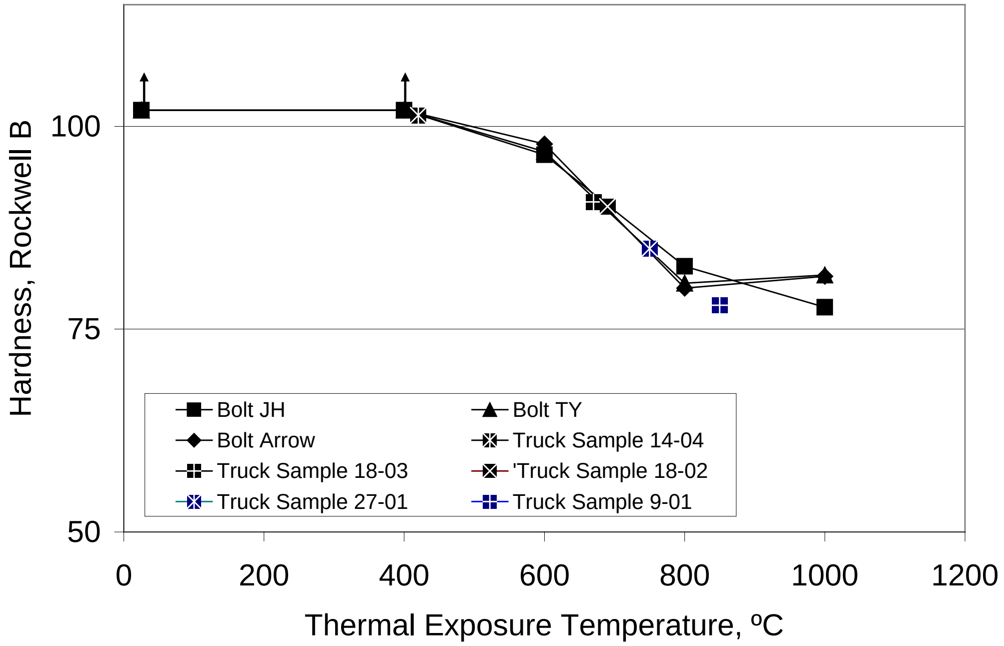


Figure 6. Effect of exposure temperature on the hardness of truck samples and commercially available Grade 5 bolts

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 from materials analyses of samples taken from the incinerated vehicles. In addition to aluminum alloys, many copper-based alloys including brass were collected and analyzed. Almost all of the copper-based alloys showed no signs of incipient melting, except for a melted brass ferrule which indicated a localized tunnel temperature of at least 884 °C (1,623 °F) by the melting point analysis. The temperatures determined from the materials analyses fall within the expected range of free burning fires with the fuel sources involved. While the temperatures witnessed are generally in the range of those prescribed in the NRC regulatory HAC fire, evaluations of transportation package response to this fire may be conducted in the future.

A fire model was developed to simulate the Newhall Pass tunnel fire. The model accounted for many of the conditions including tunnel geometry, vehicle geometry, fire sources, and local weather. The results of these simulations are preliminary and will be discussed in future papers.

ACKNOWLEDGMENTS

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