Cone Calorimeter Testing of Under Hood Insulation

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Dr. Ken Digges
Motor Vehcile Fire Research Institute
1334 Pendleton Court
Charlottesville, Virginia 22901

Authors:
Ed Fournier
Tim Bayne

Preface

This report constitutes the final deliverable for the Motor Vehicle Fire Research Institute's purchase order dated May 24, 2005 to investigate the fire retardant properties of under hood insulation.

The results of the cone calorimeter tests presented were conducted at the Institute for Research in Construction, National Research Council Canada with the support of Senior Research Officer Dr. Joseph Su.

The opinions expressed herein are those of Biokinetics and Associates Ltd. and do not necessarily reflect those of the Motor Vehicle Fire Research Institute.

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1. Introduction

Research conducted for the Motor Vehicle Fire Research Institute to investigate the use of fire safety technologies, in 2003 model year vehicles, identified the use of under hood insulation as a potential fire preventative feature [Ref. 1]. It is speculated that heat from an under hood fire would melt the mounting hardware supporting the under hood insulation allowing it to descend onto the engine and smother the fire.

The research included a visual inspection of 89 vehicles from the North American market in which the presence of under hood insulation was found in 74 instances. In those instances, however, the fire retardant properties of the insulating materials could not be ascertained by visual inspection alone.

The work reported on herein evaluated the fire retardant properties of under hood insulation from a sub sample of vehicles representing various manufacturers and classes of vehicles such as SUVs, passenger cars, minivans and pickup trucks.

Test coupons cut from the sample insulating liners were tested to assess their fire retarding properties according to an ASTM standard test procedure. The mounting hardware used to affix the liners to the under side of the hood were also tested to determine if their materials would melt or distort sufficiently to allow the insulating materials to fall.

The results of the testing are contained herein.

2. Selection of Test Specimens

Twenty samples of under hood insulation and mounting hardware were purchased for testing. As indicated the samples were selected from a cross section of vehicles from different manufacturers which included pickup trucks, SUVs, vans and passenger cars. The vehicles included in the test program are presented in Table 1.

Table 1: Vehicles included in the test program.

No.	Make	Model	Type
1	Chevrolet	S-10	Pickup
2	Ford	Ranger	
3	Ford	F-150	
4	GMC	Sierra	
5	Nissan	Frontier	
6	BMW	X5	SUV
7	Chevrolet	Suburban	
8	Ford	Explorer	
9	Jeep	Grand Cherokee	
10	Kia	Sportage	
11	Toyota	4 Runner	
12	Dodge	Caravan	Vans
13	Ford	Freestar	
14	Toyota	Sienna	
15	Dodge	Neon (SX 2.0)	Passenger Cars
16	Ford	Taurus	
17	Honda	Accord	
18	Mercedes	C320	
19	Toyota	Corolla	
20	Volkswagen	Jetta	

During previous work which reviewed the state-of –the-art in the fuel system of 2003 model year vehicles [Ref. 1], it was suggested by both Ford and Toyota dealerships that the under hood insulation in their F-150 and Sienna respectively were designed to descend and smother an engine compartment fire. For this reason vehicles from each of these manufacturers were included in each of the categories in Table 1.

3. Test Methodology

3.1 Under Hood Insulation Fire Resistance

The fire resistant properties of the under hood insulation were evaluated with a cone calorimeter according to the test procedures of ASTM E 1354-03 [Ref. 2].

The cone calorimeter test subjects a 10cm x 10cm material coupon to a known constant radiant heat flux. From the materials behaviour under the heat load the ignitability, heat release rates, mass loss rates, effective heat of combustion and visible smoke development of materials are determined. The test apparatus is shown in Figure 1 and a close-up of the test sample is shown in Figure 2.

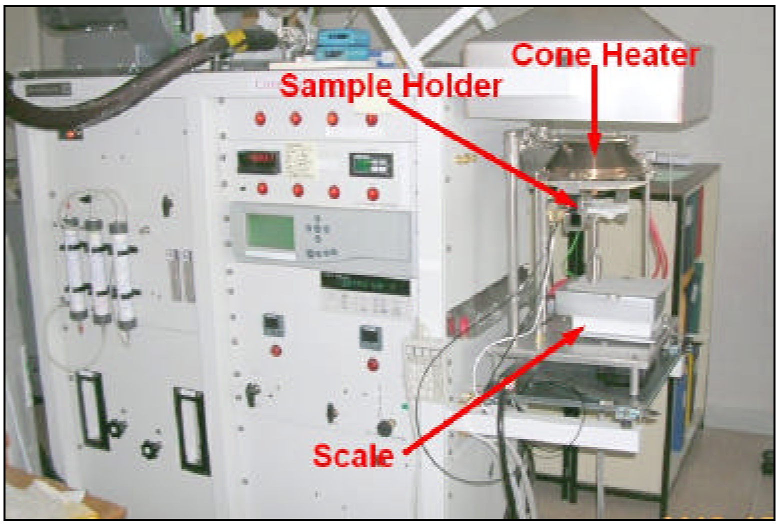


Figure 1: Cone Calorimeter test apparatus.

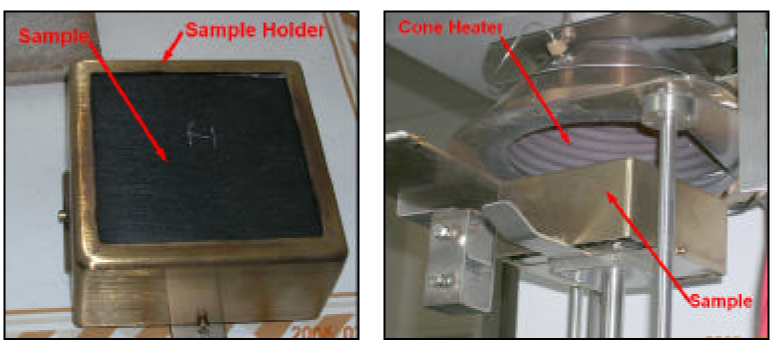


Figure 2: Close-up of a test sample and the cone heater element.

The heat flux exposure was maintained at 35 kW/m^2, which is similar to the median exposure used by Carpenter et al [Ref. 3] in their evaluation of the fire resistance of under hood components. The samples were exposed to the radiant heat source for a nominal duration of 1200 s (20 min).

Prior to testing the samples were stored in a conditioned room at 23°C and 50% relative humidity.

Typically a cone calorimeter test requires three specimens of each material to be tested. However, only an initial screening of the materials was desired by MVFRI so only one sample of each material was used. In general the under hood liners were not homogeneous with thicknesses and/or composition that varied across the liner. It must be noted that if tested these additional coupons can not be counted as exact duplicate test samples because of the differences in sample mass, thickness, uniformity or composition.

The cone calorimeter testing was conducted by the National Research Council Canada's Fire Research Program.

3.2 Mounting Hardware

The mounting clips for each under hood insulation sample were also tested to determine at what temperature they would melt or deform sufficiently to release the insulating liner from its design position.

The test set-up comprised a sample coupon of under hood insulation affixed to a rigid steel fixture with a mounting clip appropriate for the specific insulating sample. A small mass equivalent to the hood liner mass divided by the number of mounting points used in its installation was suspended from the test coupon. A thermo couple was placed in close proximity to the test sample to measure the temperature at which the insulation sample was released from its mounting.

The complete test setup was placed in a cool oven. The temperature inside the oven was increased and monitored until the under hood insulation sample disengaged from the steel fixture which nominally occurred within 10 to 15 minutes. An example of a typical test set-up is shown in Figure 3.

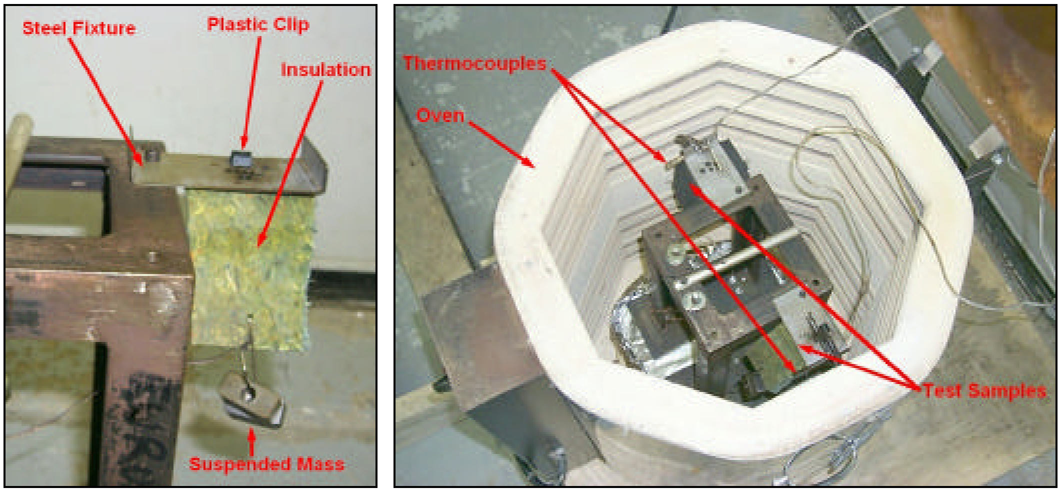


Figure 3: Typical mounting hardware test set-up.

The heat from an engine fire would only heat the exposed surface of the mounting clip. However, in the test set-up utilized the heat was applied to both ends of the clip which would result in a shorter duration for the clip to attain the melting temperature required for the insulation coupon to be released.

4. Test Results and Discussion

4.1 Under Hood Insulation Cone Calorimeter Results

The results of the Cone Calorimeter tests on the under hood insulation samples are summarized in Table 2.

Table 2: Summary of Cone Calorimeter Test Results.

Test No.	Vehicle		Initial Mass (g)	Time (s)		Peak HRR (1) (kW/m^2)	Mass Loss (2)	
	Make	Model		ignition	flameout		(g)	(%)
1	BMW	X5	9.49	6	177	314.32	8.50	89.5
2A	Chevrolet	S10	5.05	6	14	38.83	0.02	0.3
2B			3.90	3	12	52.61	0.22	5.6
3	Chevrolet	Suburban	5.88	6	65	91.20	0.98	16.6
4	Dodge	Caravan	18.17	12	470	67.32	13.47	74.1
5A	Dodge	Neon SX 2.0	4.68	NI (3)	NI	12.80	1.1	23.4
5B			4.71	NI	NI	9.51	(5)< 0.5	< 10.6
6	Ford	Explorer	7.56	5	178	60.73	3.14	41.6
7A	Ford	F150	5.66	NI	NI	12.33	1.48	26.2
7B			6.28	9	14	2.8	0.06	1.01
8A	Ford	Ranger	8.01	7	158	43.49	2.21	27.6
8B			7.11	NI	NI	9.28	4.51	63.5
9	Ford	Taurus	6.30	6	132	47.25	1.78	28.3
10	Ford	Freestar	9.45	5	130	49.01	2.26	24.0
11	GMC	Sierra	6.07	6	45	92.19	0.9	14.9
12	Honda	Accord	9.96	7	216	86.90	6.51	65.3
13A	Jeep	Grand Cherokee	5.61	5	200	17.66	(4) 2.83	50.4
13B			5.64	7	14	27.61	0.11	2.0
14	Kia	Sportage	17.35	11	318	132.12	12.92	74.5
15A	Mercedes	C320	4.26	11	91	214.54	3.02	71.0
15B			7.25	NI	NI	7.51	(5) 2.00	27.6
16A	Nissan	Frontier	10.26	6	22	48.99	0.28	2.7
16C			9.83	16	20	3.20	0.00	0.0
17	Toyota	4-runner	8.05	121	162	35.78	0.41	5.1
18	Toyota	Corolla	10.59	10	32	36.09	0.0	0.0
19	Toyota	Sienna	7.19	8	20	45.05	0.29	4.1
20	Volkswagen	Jetta	10.84	9	205	182.75	6.41	59.1

Notes:

1. HRR – heat release rate.
2. For samples that ignited the mass loss was calculated at flameout time. For samples that did not ignite mass loss was calculated relative to the end of the test (nominally 1200s).
3. NI – no ignition.
4. The time to flameout was difficult to determine.
5. Error with the scale reading. Mass loss estimate by the technician following the test.
6. Shaded test numbers indicate uneven sample thickness.

The letter designations in the test number indicated in Table 2 represent a second or third test on a test coupon cut from the same liner. As indicated previously they may not necessarily represent duplicate tests.

The duration of the test for the purpose of calculating the mass loss was taken as the time of ignition to the flameout time. If ignition did not occur the full duration of the test, nominally 1200s, was used in the calculations. It is therefore possible for a non igniting sample to produce a larger percentage mass loss due to the production of smoke or fumes from a sample that smoulders for the full duration of the test.

The time to ignition, obtained from a cone calorimeter test, is a strong indicator of a material's fire resistance. The longer it takes for a sample to ignite the more resistant the material is to burning. If a material does ignite, the output parameter of most importance is the peak heat release rate (HRR) which is a strong indicator of the material's volatility and ability to sustain ignition. Materials that exhibit HRRs that are close to or below that of the applied heat source would have trouble sustaining combustion if the heat source is removed. Conversely, the higher the HRR the more combustible the material and the more likely they will contribute to an under hood fire.

Referring to the cone calorimeter results summarized in Table 2, 5 of the 27 under hood insulation samples tested exhibited a high level of fire resistance and did not ignite (samples 5A, 5B, 7A, 8B and 15 B). Of the samples that did ignite, seven exhibited a relatively short time to flameout with comparatively low peak heat release rates that were close to or below the exposure source of 35 kW/m^2 (samples 2A, 7B, 13A, 13B, 16C, 17 and 18). These 7 materials with low HRR and the 5 none igniting samples would have the most promise in a fire blanket concept and at the very least would contribute the least to fire spread.

Seven of the insulation samples were essentially consumed during the test with peak HRRs ranging from 74% to almost 800% higher than the applied radiant heat load. These materials would likely contribute to a fire.

An apparent anomaly was encountered with the measurement of mass loss in test 2A therefore a second test of a sample from the Chevrolet S10 was conducted (test 2B). Upon completion of the retest, both tests were considered valid with similar flaming duration and low mass loss.

Test 5B on the liner from the Dodge Neon was meant to be a true repeat test of 5A however an abnormal mass gain was observed. The mass loss presented was estimated by the technician.

A repeat test was performed on the Ford F150 insulation (tests 7A and 7B). In the first test there was no ignition but dense fumes were emanating from the sample. In the repeat test the dense fumes were present followed by a flash ignition that burned for less than 5 seconds, however, there was almost no heat release and the mass loss during this time was less than 0.05g.

The hood side of the Ford Ranger's insulation panel is covered with a metal foil with the fibrous side facing the engine as shown in Figure 4. The reason for the use of the foil in this configuration is not known. Ignition was observed when the sample was tested in the standard orientation (test 8A). A test was also performed with the metal foil side of the sample exposed to the heat load. In this orientation a low peak HRR was observed and ignition did not occur however, a larger amount of mass loss was recorded due to smouldering of the sample for the full duration of the test.

a) b)

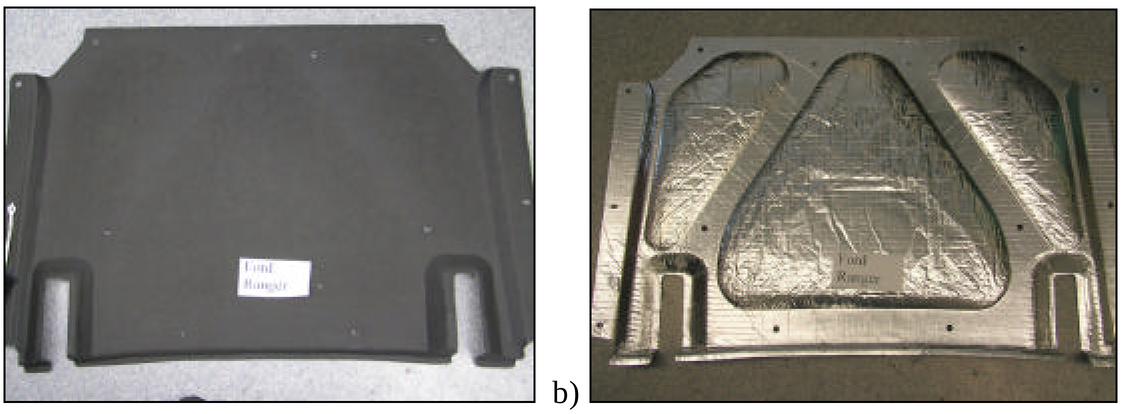


Figure 4: Ford Ranger under hood insulation: a) engine side, b) hood side.

The Kia Sportage insulation sample (test 14A) was converted entirely into white ash by the completion of the test at 1274s.

A section of the Mercedes C320 under hood insulation was covered with a metal foil as shown in Figure 5. Interestingly, unlike the replacement liner that was purchased for the cone testing, there was no foil present in C320 vehicle that was inspected. In examining the engine compartment there was no apparent reason for the use of the foil (see Figure 6). Nevertheless, to evaluated the effect of the foil, insulation samples from both the fibre exposed and foil exposed surfaces of the liner were tested (test 15A and 15B respectively). Similarly to the Ford Ranger tests, the foil covered surface did not ignite whereas the exposed insulation ignited in 11s. These findings suggests that the application of a metal foil to the insulating panels can be used to prevent material ignition.

Figure 5: Replacement Under hood insulation for the Mercedes C320.

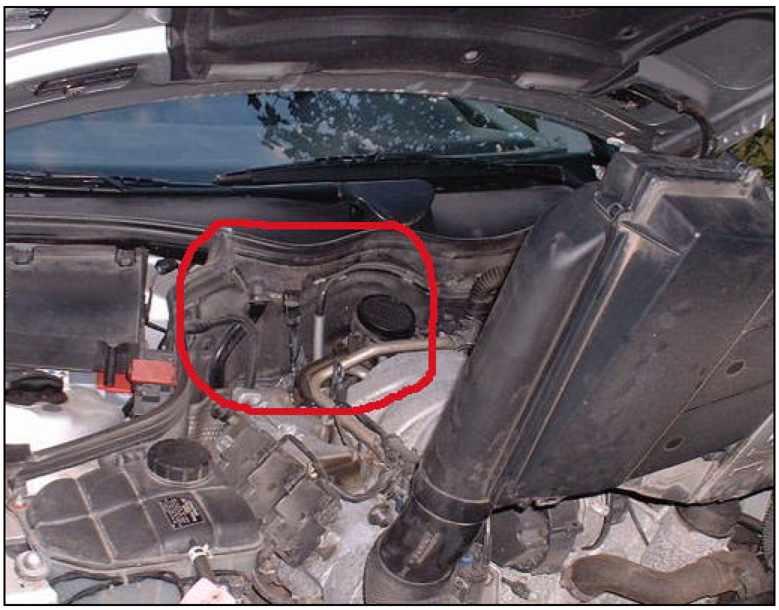


Figure 6: Region that would be under the foil of Mercedes C320 replacement hood liner.

The two samples from the Nissan Frontier represented a different composition of the same liner. Sample 16A was thick and loosely packed fibre whereas, 16C comprised a thin, stiff board of the same fibres but more densely packed. Both samples produced little mass loss however, sample 16C had a higher peak heat release rate associated with the burning off of a thin outer fabric which was loosely bonded to the liner fibres.

4.2 Mounting Hardware Oven Tests

The temperatures at which the mounting hardware plastic clips melted sufficiently for the insulation coupon to disengage are presented in Table 3.

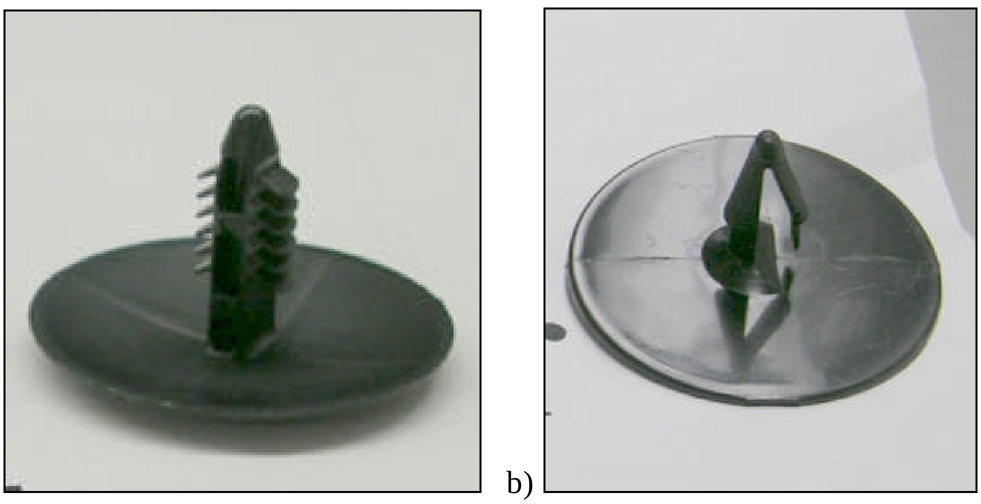
Table 3: Results of mounting hardware oven tests.

No.	Make	Model	Suspended Mass (kg)	Insulation Release Temperature (°C)
1	Chevrolet	S-10	0.044	144
2	Ford	Ranger	0.068	139
3	Ford	F-150	0.041	244
4	GMC	Sierra	0.092	133
5	Nissan	Frontier	0.066	263
6	BMW	X5	0.053	262
7	Chevrolet	Suburban	0.088	138
8	Ford	Explorer	0.077	254
9	Jeep	Grand Cherokee	0.048	244
10	Kia	Sportage	0.056	205
11	Toyota	4 Runner	0.063	245
12	Dodge	Caravan	0.067	144
13	Ford	Freestar	0.081	240
14	Toyota	Sienna	0.034	230
15	Dodge	Neon (SX 2.0)	0.025	239
16	Ford	Taurus	0.061	244
17	Honda	Accord	0.096	168
18	Mercedes	C320	0.020	268
19	Toyota	Corolla	0.079	141
20	Volkswagen	Jetta	0.084	232

As seen in the Table 3, the insulation mounting clips from all the tested vehicles melted. The temperatures required for the insulation samples to be released ranged from 133 °C to 268 °C. Presumably the lower the insulation release temperature the better otherwise, the possible benefits of an under hood liner that has fire retardant properties may be minimized the longer it stays affixed to the underside of the hood. Additionally, if the mounting clips do not melt and the under hood liner does not disengage the possible fire preventative benefits would be negated completely.

As a point of reference, typical temperatures of an under hood fire, measured in full scale tests conducted by Santrock [Ref. 4], range from 700 °C to 1000 °C with temperatures exceeding 268 °C in 30 seconds or less. Therefore, it is likely that the difference between the time to achieve 133 °C compared with the time required to attain 268 °C is insignificant.

The insulation release temperature of four of the five Ford vehicles tested was nominally 244 °C. Each of these vehicles used the same type of mounting clip For the fifth vehicle, the Ford Ranger, the insulation release temperature was only 139 °C. Although the mounting clip for the Ranger appeared to be fabricated of similar material as the other mounting clips its design differed from the others as seen in Figure 7. The design differences could possibly influence the deformation pattern and the required temperature to sufficiently deform the clips to allow the test coupon to disengage.



a) b)

Figure 7: a) Insulation clip found in four Ford vehicles tested,
b) insulation clip from the Ford Ranger.

The three Toyota vehicles employed the same insulation clip shown in Figure 8. The measured insulation release temperatures in two instances were similar at 230 °C and 245 °C. However, with the Corolla, the third case using the same clip, the release temperature was measured at 141 °C. It is unclear why a lower temperature was sufficient for the insulation sample to release. A possible explanation is that suspended weight was higher which made it easier for the clip to deform.

Figure 8: Insulation clip from the Toyota Vehicles.

The insulation release temperatures for all the GM vehicles were similar ranging from 133 to 144.

5. Summary and Conclusions

The under hood insulation from 20 vehicles were tested using a cone calorimeter to assess their fire resistive/burn properties. Including the repeat tests a total of 27 tests were performed. The cone tests were conducted according to the procedures in ASTM E 1354-03 standard. The mounting clips for each of the liners were also tested to determine the temperature at which they would melt, disengaging the liner from the vehicle hood.

Of the insulating under hood liners tested 5 did not ignite. An additional 7 insulation samples that did ignite exhibited a short time to flameout with comparatively low peak heat release rates. These samples with the inclusion of the non igniting samples show the most potential for smothering an engine fire.

The Cone Calorimeter testing indicated that the application of a metal foil to the engine facing side of an under hood insulting panel can significantly enhance the fire resistance of an insulating material by preventing ignition.

If an under hood insulation panel is to smother a fire the mounting clips affixing it to the hood must disengage from the hood under high heat conditions of an engine compartment fire. The mounting clips for the under hood insulation from the twenty different vehicles tested disengage from the supporting structure at temperatures ranging from 133 °C to 268 °C. Furthermore the results seemed to indicated that the design of the mounting clips may have an influence on the deformation pattern and the temperature required for the insulating sample to disengage.

Given that fire resistant under hood insulating panels were identified amongst the small sample of vehicles examined, the possibility of the panels acting as a fire blanket and smothering and engine fire is feasible. However, the effectiveness of such a system can not be determined strictly from the component tests that were performed. Ultimately, the typical temperatures of an engine compartment fire need to be lower than the flaming temperature of the insulation and higher than the melting temperature for the mounting clips. Simulated engine compartment fires are needed to determine the actual effectiveness of a fire resistive panel at smothering a fire.

6. References

Ref. 1 Fournier, E., Bayne, T., Kot, J., "Review of the State-of-the-art In Fuel Tank Systems – Phase II", Biokinetics report R03-01, May 12, 2003.

Ref. 2 ASTM E 1354-03, Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter, American Society of Testing and Materials, West Conshohocken, PA, 2003.

Ref. 3 Carpenter, K., Janssens, M., Sauceda, A., "Using the Cone Calorimeter to Predict FMVSS 302 Performance of Automotive Components", from the Society of Automotive Engineers 2005 World Congress, Fire Safety Session, Special Publication SP-1939, SAE 2005-01-1557, Society of Automotive Engineers, Warrendale, PA, 2005.

Ref. 4 Santrock, J., "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 3: Propagation of an Engine Compartment Fire in a 1996 Van Passenger", August 2001, Docket # NHTSA-1998-3588-119, General Motors Corporation.