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Flammability of Under Hood Insulation Materials

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ABSTRACT

Vehicle inspections have been conducted to identify the use of fuel system fire safety technologies. Of the 89 vehicles inspected, 74 incorporated insulation on the inside of the hood. The flammability of the under hood insulation identified during the vehicle inspections could not be ascertained by visual inspection alone. Consequently, a test program was undertaken to assess the flammability properties of under hood insulation liners from a sample of 20 different vehicles using a cone calorimeter test prescribed by ASTM E 1354-03. The mounting clips for each liner were also tested separately to estimate the temperature required for the clips and liner to disengage from their design locations.

The results of the calorimeter tests and the mounting clip tests are presented.

INTRODUCTION

Research sponsored by the Motor Vehicle Fire Research Institute was conducted to investigate the use of fire safety technologies, in 2003 model year vehicles, [Ref. 1]. The research comprised a visual inspection of 89 vehicles from the North American market in which the presence of under hood insulation was found in 74 instances. During the course of the inspection of two vehicles, it was suggested that heat from an under hood fire would melt the mounting clips supporting the under hood insulation allowing it to fall onto the engine. The visual inspections alone, however, were insufficient to determine the flammability of any of the under hood liners that were encountered.

Under hood liners from a subset of 20 vehicles representing various manufacturers and classes of vehicles were purchased for a direct assessment of their flammability. Test coupons cut from these samples were tested using a cone calorimeter following the ASTM E 1354-03 test procedure [Ref. 2]. The mounting clips 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 during an engine fire.

SELECTION OF TEST SPECIMENS

The under hood insulation liners were selected from a cross section of 2003 model year vehicles representing different manufacturers and vehicle types. The vehicles included in the test program are presented in Table 1.

Table 1: Under hood insulation liners tested.

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	Van
13	Ford	Freestar	
14	Toyota	Sienna	
15	Dodge	Neon (SX 2.0)	Passenger Car
16	Ford	Taurus	
17	Honda	Accord	
18	Mercedes	C320	
19	Toyota	Corolla	
20	Volkswagen	Jetta	

TEST METHODOLOGY

FLAMMABILITY OF UNDER HOOD INSULATION

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

The cone calorimeter test subjects a 10 cm x 10 cm material coupon to a known constant radiant heat flux. From the materials' behavior 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 cone calorimeter test apparatus is shown in Figure 1 and a close-up of a typical test sample is shown in Figure 2.

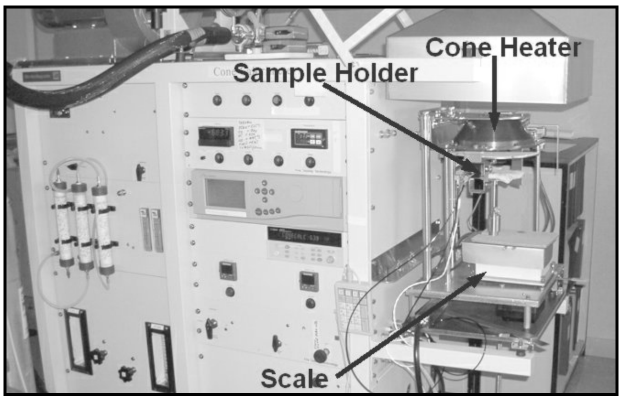

Figure 1: Cone calorimeter test apparatus.

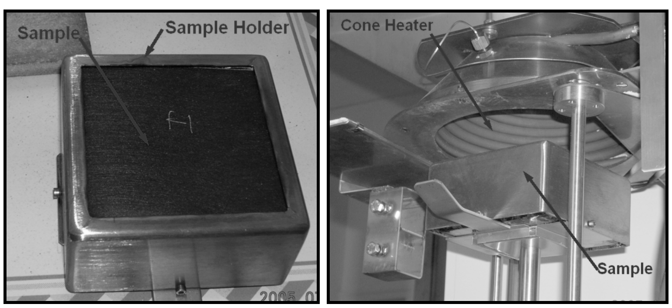

Figure 2: Close-up of a test sample and the cone heater element.

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 and by Battipaglia et al in their evaluation of automotive materials [Ref. 4]. 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 for a minimum of 24 hours.

Typically, a cone calorimeter test requires three specimens of each material to be tested to obtain average results. However, an initial screening of the materials was desired so only one sample of each material was tested. In general, the under hood liners were not homogeneous, with thickness and/or composition that varied across the liner. For this reason, additional tests of coupons from the same liner are not necessarily duplicate or repeat tests.

The cone calorimeter testing was conducted by the National Research Council Canada's Institute for Research in Construction.

MOUNTING HARDWARE

The mounting clips for each under hood insulation sample were also tested to determine the temperature at which 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 thermocouple was placed in close proximity to the test sample to measure the temperature at which the insulation sample released from its mounting.

The complete test setup was placed in a cool oven. The temperature inside the oven was slowly increased and monitored until the under hood insulation sample disengaged from the steel fixture. This nominally occurred within 10 to 15 minutes. This time however, is not representative of that required for the clips to melt in an engine compartment fire, were the onset of heat would be faster. An example of a typical test set-up is shown in Figure 3 and Figure 4.

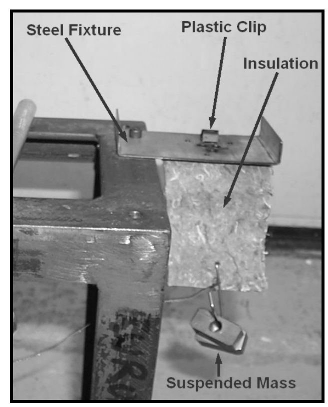

Figure 3: Fixture for testing mounting clips.

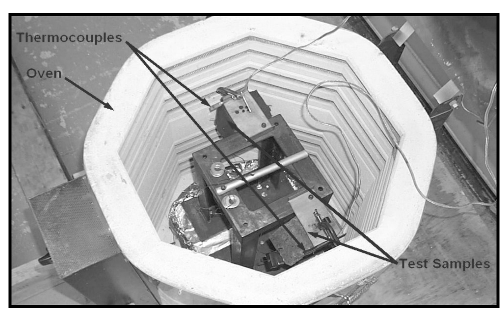

Figure 4: Typical mounting hardware test set-up.

In an engine compartment fire the heat from the fire would heat only 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, under the test conditions, for the clip to attain the melting temperature required for the insulation coupon to be released.

TEST RESULTS AND DISCUSSION

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	(3) NI	NI	12.80	1.10	23.4
5B			4.71	NI	NI	9.51	(5) < 0.50	< 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	2.80	0.06	1.0
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	0.90	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	0.00	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 and was subject to technician interpretation.
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 coupon cut from the same liner but do 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. If ignition did not occur the full duration of the test, nominally 1200s, was used in the calculations.

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 an 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 flux would have trouble sustaining combustion if the heat source is removed. Conversely, the higher the HRR the more combustible the material.

Referring to the results summarized in Table 2, five test samples 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 non igniting materials would contribute the least to an engine fire.

Seven of the insulation samples offered little resistance to combustion and were essentially consumed during the test with peak HRRs ranging from 74% to almost 800% higher than the applied radiant heat load.

An apparent anomaly was encountered with the measurement of mass loss in test 2A, therefore, a second test of the Chevrolet S10 liner was conducted (test 2B). Upon completion of the retest, the results of both tests were deemed to be valid with similar flaming duration and low mass loss, although the second test had a higher peak release rate.

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 due to an error with the load cell. 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 uncovered fibrous side of the panel facing the engine as shown in Figure 5. Ignition was observed when the sample was tested in the standard orientation (test 8A). A test was also performed in a non standard orientation with the metal foil exposed to the heat load (test 8B). 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 smoldering of the sample for the full duration of the test.

a)
b)

Figure 5: Ford Ranger under hood insulation: a) engine side, b) hood side.

The two tests of the Jeep liner (test 13A and 13B) produced very different flameout times. In the first test a low level creeping flame persisted for almost 200 seconds whereas, in the second test, the flame extinguished in 7 seconds. The long flaming period of the first test contributed to the larger mass loss. Nevertheless, both samples produced peak heat release rates below that of the applied heat load.

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

A section of the Mercedes C320 under hood insulation was covered with a metal foil as shown in Figure 6. A test coupon from both the fiber exposed and foil exposed surfaces of the liner were tested (test 15A and 15B respectively). Similarly to the Ford Ranger test results, the foil covered surface did not ignite whereas the exposed insulation ignited in 11s. These findings suggest that the application of a metal foil to the insulating panels can be used to suppress material ignition when facing the engine.

Figure 6: Under hood insulation from the Mercedes C320.

The two liner samples from the Nissan Frontier represented a different composition of the same liner. Sample 16A was thick, comprised of loosely packed fiber whereas, 16C comprised a thin, stiff board of the same fiber 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 fibers.

MOUNTING HARDWARE OVEN TESTS

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

Table 3: Results of mounting hardware oven tests.

No.	Make	Model	Suspended Mass (kg)	Release Temp. (°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, all the insulation mounting clips melted. The temperatures at which the insulation samples disengaged from the test fixture ranged from 133 °C to 268 °C.

As a point of reference, typical peak temperatures of an under hood fire range from 700°C to 1000 °C with temperatures exceeding 268° C in less than 30 seconds [Ref. 5,6,7]. That being said, the difference in time to achieve temperatures of 130 °C at the mounting point compared to the time required to attain 268 °C would be insignificant. As a further reference, engine compartment temperatures, under normal operating conditions, range between 50 °C and 70 °C as measured at the hood. These temperatures were observed in a study that measured the engine temperatures of four vehicles under various driving conditions [Ref. 8].

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 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)

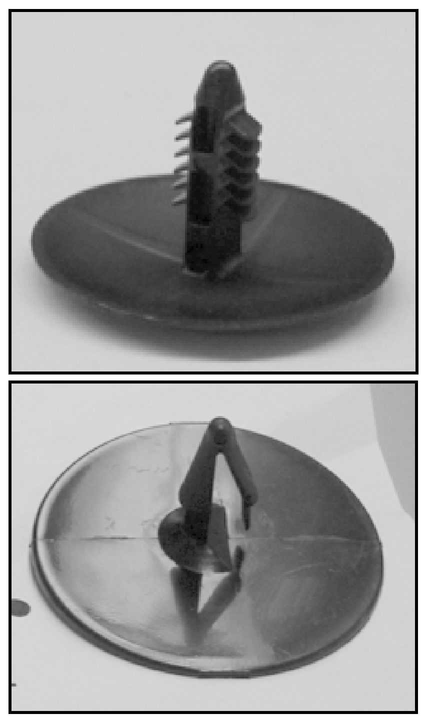

Figure 7: a) Insulation clip found in four Ford vehicles tested, b) insulation clip from the Ford Ranger.

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 the suspended weight was 16 grams heavier than the weight used on the 4 Runner sample and 45 grams heavier than the Sienna sample. This extra mass may have made it easier for the clip to deform and release.

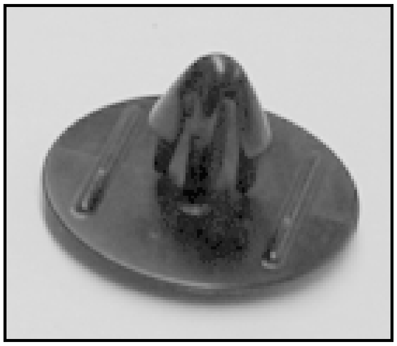

Figure 8: Insulation clip from the Toyota Vehicles.

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

SUMMARY AND CONCLUSIONS

The under hood insulation from 20 vehicles was tested using a cone calorimeter to assess their flammability. 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. The results obtained are specific to the insulation liners and mounting clips tested.

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 would contribute the least to 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 suppressing ignition.

The mounting clips for the under hood insulation tested disengage from the supporting structure at temperatures ranging from 133 °C to 268 °C. Furthermore, the results seemed to indicate 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.

ACKNOWLEDGMENTS

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