Fire tests of hollow-core specimens with and without roof insulation

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Fire tests were conducted on 8-in. hollow-core specimens 40 x 48-in. in plan. Specimens were tested with and without roof insulation to determine the effect of the insulation material on the temperature of the strand.
Specimens were oriented horizontally with the central 33 x 33-in. area of the underside of each specimen exposed to fire. No load was applied. Strand temperatures were monitored for more than 3 hr.
Test results indicate that strand temperatures were not significantly affected by the presence of the roof insulation.

In recent years, efforts to conserve energy used to heat and cool buildings have resulted in the increased use of insulating materials in a structure.

It has been observed during fire tests that the use of roof insulation has resulted in an increase in the temperatures of the supporting members of steel roof construction.

A concern has been expressed that reinforcing steel temperatures might increase in concrete roof construction, especially if thicker layers of insulation are required.

Test information has been published[1] which shows that strand temperatures in prestressed concrete stemmed roof units are not significantly changed when insulation is used.

Similar information has not been available for hollow-core roof units. Consequently, two fire tests were carried out to determine the temperature of the prestressing steel in hollow-core roof units with and without insulation.

It should be noted that no attempt was made or intended with these small-scale specimens to verify a fire-duration period for the hollow-core units used in the tests, nor should such an interpretation be permitted.

Similarly, no measurements were made to emphasize the improvement in heat transmission through a roof assembly incorporating roof insulation, since this is well established by other tests.[1]

Test Specimens

Each test specimen consisted of two 8-in. normal weight concrete hollow-core units, 24 in. wide and 40 in. long. One unit contained four ½-in. diameter strands; the other unit four ⅜-in. strands. Concrete cover over the strand was 1½ in. for both units.

To measure strand temperature, a thermocouple (*T/C*) was located at midlength and midheight of each strand. The thermocouples were attached to the stressed strand in the casting bed at the fabrication plant.

Three days after fabrication, the hollow-core units arrived at the Portland Cement Association Fire Research Laboratory. A Monfore-type humidity well[2] was installed in one of the units at the location shown in Fig. 1. The moisture content of all of the units was assumed to be the same as that determined at this location.

All four units were placed in a drying kiln for 7 days. This kiln was maintained at 130 to 140 F and 0 to 25 percent relative humidity. After the 7-day drying period, the relative humidity at the well location was 75 percent.

Fig. 1 shows details of the test specimen with roofing insulation. The rigid type insulation material that was used had a thickness of 2¾ in., a nominal weight of 1.15 psf, and a thermal resistance, *R*, equal to 16.7.

Material properties were obtained from the nanufacturer. A standard built-up roofing[3] consisted of three-ply, 15-lb felt and not in excess of 1.20 psf of hot-mopping asphalt. No gravel surfacing was applied.

Test Method

When the concrete reached the desired moisture condition for test, one unit containing ⅜-in. strand and another with ½-in. strand were placed side by side in a horizontal position on the furnace. A fast-setting mortar was used to seal the center joint. A 6-in. diameter by 2-in. thick plug of mineral wool insulation was fitted tightly into each end of the voids to prevent loss of heat and reduce air flow through the voids.

The specimen tested with roof insulation had a vapor barrier of two-ply, 15-lb felt on the top surface of

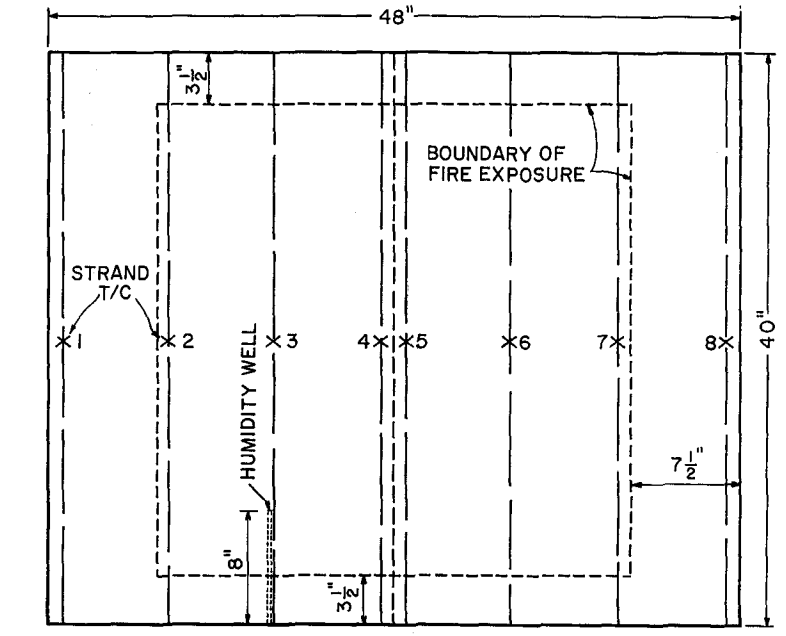

Fig. 1. Test specimen with roof insulation.

the hollow-core units. A 2¾-in. rigid-type insulation material, with a standard built-up roof already applied to it, was placed on the vapor barrier to complete the roof insulation system. All sides of both test specimens were protected by a 2-in. thick solid lightweight insulating material held in place by taut metal strapping.

The hollow-core units were tested in an unloaded condition. The central 33x 33-in. area of the specimens was exposed to the fire. Consequently, only Strands 3, 4, 5, and 6 were located in the central zone of the furnace.

Thermocouple numbers correspond to strand numbers shown in Fig. 1. Strands 2 and 7 were a few inches from the sides of the heated zone while Strands 1 and 8 were outside of the heated zone. Strand temperatures were monitored for the duration of each test.

For the slab without insulation the test was terminated at 3 hr 6 min; for the test specimen with insulation, 3 hr 12 min. At these times, the temperatures of Strands 3, 4, 5, and 6 exceeded 1000 F. This temperature was arbitarily chosen as the upper limit for comparing performance of the specimens.

Furnace temperatures, as measured by two thermocouples located in the furnace 12 in. below the test slab, were also monitored throughout the tests. The maximum variations for the two tests from the Standard ASTM E119 time-temperature curve are shown in Fig. 2.

Analysis of Results

Furnace atmosphere temperatures and prestressing strand temperatures for the two tests are reported in Tables 1 through 5.

Although Strands 3, 4, 5, and 6 were located in the most uniform temperature zone of the furnace, temperatures were averaged to compensate for crack-

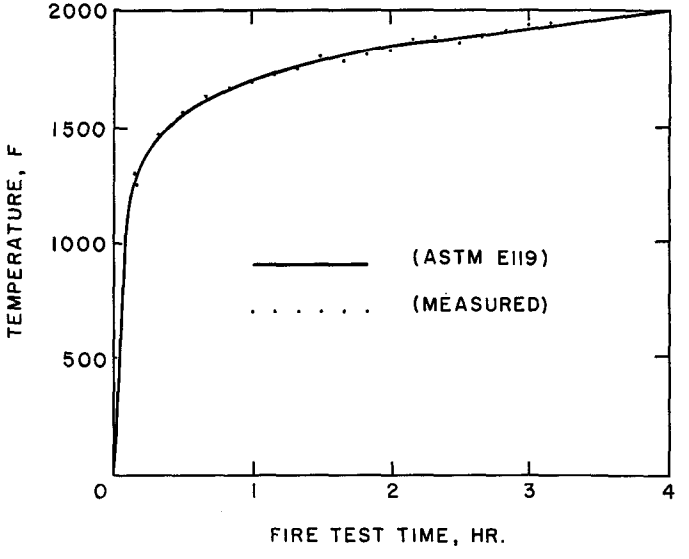

Fig. 2. Furnace atmosphere temperatures.

ing on the bottom of the slabs and slight differences in cover thicknesses and thermocouple locations.

Both test specimens developed transverse and longitudinal cracks on the top surfaces of the hollow-core units. A longitudinal crack, on the bottom, parallel to Strand 3 and about 1 in. from it, occurred early in the test of the specimen with roofing insulation. As a result of this crack higher temperatres were recorded for Strand 3 as shown in Table 4.

Fig. 3 shows a comparison of strand temperatures for slabs with and without insulation. The top graph shows the average temperatures for ⅜-in. diameter strands (Strands 3 and 4) for both tests. Similar information for ½-in. diameter strands (Strands 5 and 6) are

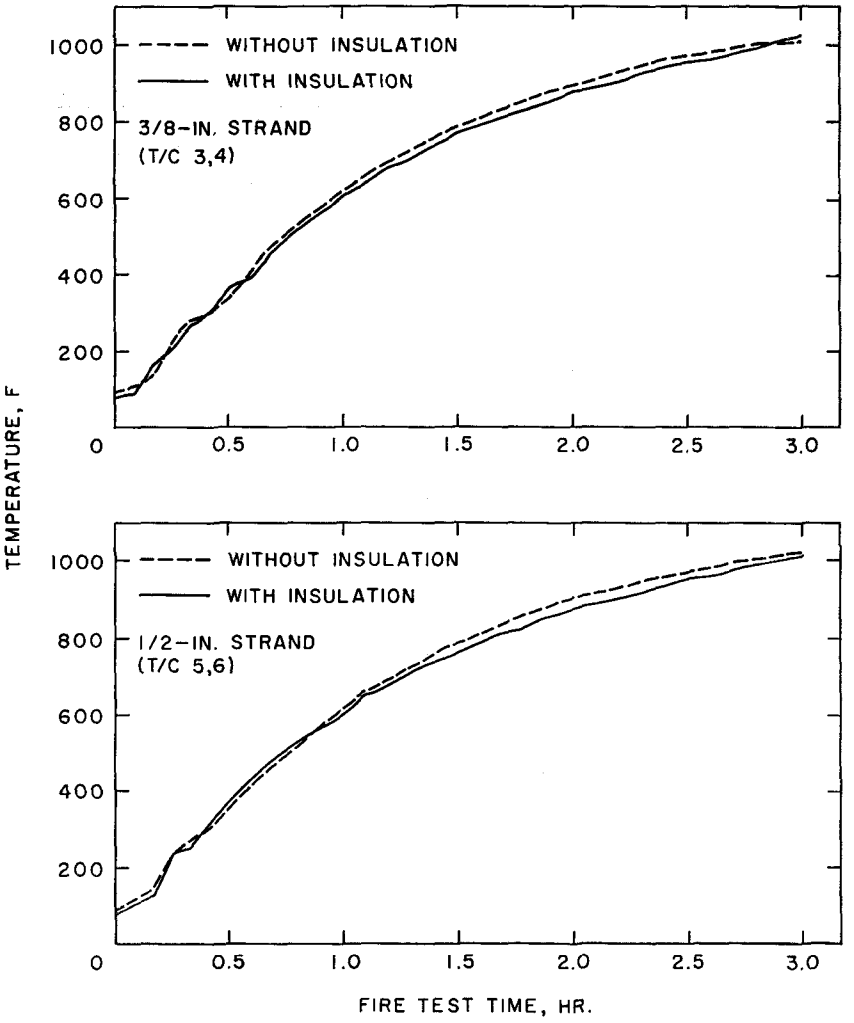

Fig. 3. Comparison of average strand temperatures for hollow-core units with and without roof insulation.

shown in the bottom graph.

For both sizes of strand, the graphs show that the strand temperatures measured on the hollow-core units with roof insulation were not significantly different from those measured in the test with no insulation.

A comparison of the temperature data in Tables 3 and 4 for Strands 1, 2, 7, and 8, located outside of the central zone of the furnace, substantiates the above observation.

Table 1. Furnace atmosphere temperatures—Hollow-core units without insulation.

Test Time Hr: Min	Furnace Temp., F	ASTM Temp., F	Variation, F
0:00	81	68	+13
0:05	960	1000	-40
0:10	1278	1300	-22
0:15	1403	1399	+ 4
0:20	1460	1462	- 2
0:25	1510	1510	0
0:30	1565	1550	+15
0:35	1584	1584	0
0:40	1616	1613	+ 3
0:45	1635	1638	- 3
0:50	1661	1661	0
0:55	1678	1681	- 3
1:00	1696	1700	- 4
1:05	1720	1718	+ 2
1:10	1737	1735	+ 2
1:15	1750	1750	0
1:20	1764	1765	- 1
1:25	1775	1779	- 4
1:30	1817	1792	+25
1:35	1818	1804	+14
1:40	1820	1815	+ 5
1:45	1830	1826	+ 4
1:50	1835	1835	0
1:55	1840	1843	- 3
2:00	1845	1850	- 5
2:10	1878	1862	+16
2:20	1885	1875	+10
2:30	1890	1888	+ 2
2:40	1902	1900	+ 2
2:50	1913	1912	+ 1
3:00	1929	1925	+ 4
3:06	1940	1931	+ 9

Note: ASTM temperature is the time-temperature relationship given in ASTM designation E119.

Table 2. Furnace atmosphere temperatures—Hollow-core units with insulation.

Test Time Hr: Min	Furnace Temp., F	ASTM Temp., F	Variation, F
0:00	89	68	+21
0:05	930	1000	-70
0:10	1285	1300	-15
0:15	1425	1399	+26
0:20	1470	1462	+ 8
0:25	1521	1510	+11
0:30	1563	1550	+13
0:35	1590	1584	+ 6
0:40	1618	1613	+ 5
0:45	1645	1638	+ 7
0:50	1666	1661	+ 5
0:55	1680	1681	- 1
1:00	1696	1700	- 4
1:05	1718	1718	0
1:10	1735	1735	0
1:15	1748	1750	- 2
1:20	1759	1765	- 6
1:25	1770	1779	- 9
1:30	1780	1792	-12
1:35	1794	1804	-10
1:40	1791	1815	-24
1:45	1815	1826	-11
1:50	1825	1835	-10
1:55	1830	1843	-13
2:00	1838	1850	-12
2:10	1855	1862	- 7
2:20	1870	1875	- 5
2:30	1878	1888	-10
2:40	1897	1900	- 3
2:50	1915	1912	+ 3
3:00	1937	1925	+12
3:10	1948	1938	+10

Note: ASTM temperature is the time-temperature relationship given in ASTM designation E119.

Table 3. Prestressing strand temperatures—
Hollow-core units without insulation.

Test Time	Temperature, F							
Hr: Min	T/C 1	T/C 2	T/C 3	T/C 4	T/C 5	T/C 6	T/C 7	T/C 8
0:00	92	90	90	91	90	90	89	92
0:05	89	95	100	105	100	114	105	90
0:10	91	130	125	170	160	180	150	89
0:15	90	171	230	230	240	235	200	90
0:20	90	226	266	280	280	265	250	90
0:25	92	275	300	310	315	300	276	90
0:30	94	295	345	350	370	350	304	90
0:35	94	310	400	401	420	390	328	91
0:40	94	340	450	460	475	440	350	92
0:45	95	365	500	498	515	485	385	95
0:50	97	400	550	540	555	535	418	98
0:55	100	425	585	576	595	570	450	102
1:00	102	455	637	610	629	620	478	109
1:05	105	480	665	640	660	650	507	117
1:10	110	505	698	677	690	682	533	127
1:15	115	533	724	699	715	717	560	135
1:20	120	559	753	725	740	742	582	139
1:25	123	575	780	750	765	765	601	145
1:30	128	600	800	775	788	795	625	150
1:35	134	614	823	796	810	812	646	155
1:40	138	640	845	817	830	835	665	160
1:45	142	656	860	835	847	855	680	165
1:50	146	675	880	854	864	874	695	169
1:55	152	689	895	875	885	890	715	172
2:00	156	704	911	890	900	905	730	175
2:10	167	735	938	920	930	935	755	180
2:20	175	763	959	946	955	955	780	183
2:30	179	781	975	968	975	970	798	183
2:40	185	800	990	990	997	992	815	185
2:50	193	820	1003	1010	1015	1005	832	189
3:00	200	836	1017	1027	1033	1020	847	196

Note: Thermocouples T/C 1 through T/C 4 are for 3/8-in. diameter strand.
Thermocouples T/C 5 through T/C 8 are for 1/2-in. diameter strand.

Table 4. Prestressing strand temperatures—Hollow-core units with insulation.

Test Time	Temperature, F							
Hr: Min	T/C 1	T/C 2	T/C 3	T/C 4	T/C 5	T/C 6	T/C 7	T/C 8
0:00	82	82	83	83	83	83	83	83
0:05	83	89	90	98	105	99	100	83
0:10	84	125	160	160	180	160	150	90
0:15	85	160	220	225	250	210	205	90
0:20	86	225	260	282	290	245	220	90
0:25	86	260	295	315	325	308	240	90
0:30	86	290	358	360	370	368	270	90
0:35	86	315	410	380	415	430	300	90
0:40	86	345	465	435	455	472	335	92
0:45	87	385	525	465	490	528	358	93
0:50	88	425	560	510	525	560	385	93
0:55	90	442	610	528	555	605	415	95
1:00	91	475	649	572	595	645	449	100
1:05	93	495	685	590	620	685	470	101
1:10	98	528	723	617	645	710	490	108
1:15	99	545	750	635	665	740	515	113
1:20	100	571	785	660	690	765	540	118
1:25	103	595	810	685	705	790	560	120
1:30	109	620	835	710	725	815	580	125
1:35	110	638	860	720	745	835	600	130
1:40	113	652	880	738	765	852	620	133
1:45	118	672	899	755	780	870	640	135
1:50	120	690	915	770	800	895	655	141
1:55	125	700	931	785	818	901	670	148
2:00	129	720	945	810	830	910	690	150
2:10	139	743	970	830	860	940	715	155
2:20	149	775	995	870	895	969	745	163
2:30	156	795	1012	900	920	985	770	182
2:40	165	820	1030	929	945	1005	790	190
2:50	175	840	1049	955	975	1020	815	199
3:00	189	858	1062	987	998	1040	830	213
3:10	198	872	1072	1010	1028	1055	841	218

Note: Thermocouples T/C 1 through T/C 4 are for 3/8-in. diameter strand.
Thermocouples T/C 5 through T/C 8 are for 1/2-in. diameter strand.

Table 5. Average prestressing strand temperatures—Hollow-core units with and without insulation.

Test Time Hr: Min	Temperature, F			
	3/8-in. Strand - T/C 3 and 4		1/2-in. Strand - T/C 5 and 6	
	w/o insulation	w/insulation	w/o insulation	w/insulation
0:00	90	83	90	83
0:05	102	94	117	102
0:10	147	160	170	170
0:15	230	222	237	230
0:20	273	271	272	267
0:25	305	305	307	316
0:30	347	359	360	369
0:35	400	395	405	422
0:40	455	450	457	463
0:45	499	495	500	509
0:50	545	535	545	542
0:55	580	569	582	580
1:00	623	610	624	620
1:05	652	637	655	652
1:10	687	670	686	677
1:15	711	692	716	702
1:20	739	722	741	727
1:25	765	747	765	747
1:30	787	772	791	760
1:35	809	790	811	790
1:40	831	809	832	808
1:45	847	827	851	825
1:50	867	842	869	847
1:55	885	858	887	859
2:00	895	879	902	870
2:10	929	900	932	900
2:20	952	932	955	932
2:30	971	956	972	957
2:40	990	979	994	975
2:50	1006	1002	1010	997
3:00	1022	1024	1026	1019

Summary

Two fire tests of 8-in. hollow-core specimens 40x48 in. in plan were carried out. These tests were conducted to evaluate the effects of roofing insulation on the temperature of the prestressing strand.

In one test, 2¾ in. of roof insulation was placed on the side of the specimen away from the fire. In the other test, no insulation was used.

A comparison of the data obtained shows that use of the roof insulation did not result in higher strand temperatures. In fact, measurements show that at durations of 1 hr and greater, average strand temperatures were consistently a few degrees less in the insulated specimen.

Discussion of this paper is invited. Please forward your discussion to PCI Headquarters by June 1, 1976.

References

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