Part II of a three-part series on Repair of Fire Damage

Evaluating fire damage to concrete structures

When the structural condition is ambiguous, a reliable diagnosis can assure future safety and may save money in repairs

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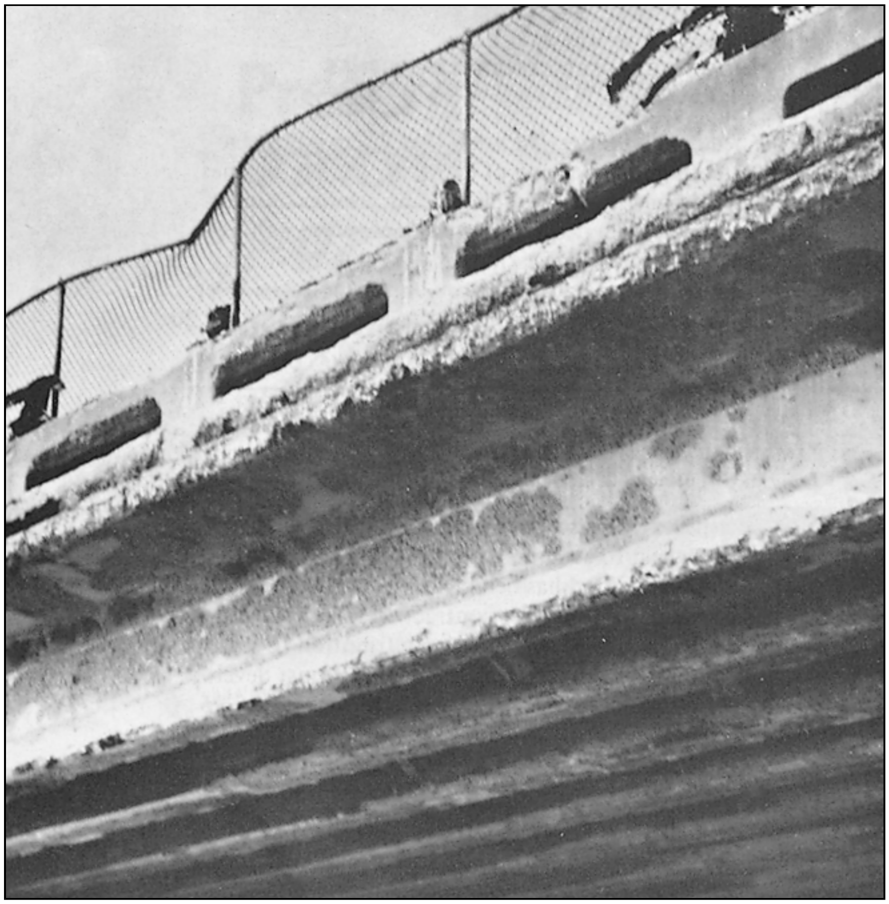

Spalling of concrete and melting of aluminum railing from gasoline truck fire below a bridge.

Several days after a fire, walls and ceilings are cold to both sight and touch. Ash and water or ice lie over everything. Concrete is likely to be spalled, exposing steel that drapes from beams in shallow arcs. Surfaces may be blackened, cracking may be visible and aluminum railings melted. By this time at least a preliminary investigation of the condition of the structure will perhaps have been made. If the first general assessment of the damage has been ambiguous, a reliable evaluation of the condition of the structure by experts becomes necessary. There will be great interest in this evaluation and considerable urgency for completing it because insurance companies will be concerned about the extent of repairs required and owners will want the structure back in service with minimum delay.

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Although the complete evaluation will begin with an examination of the condition of various materials that went through the fire, such as ceramics, furniture or metal housings, the information primarily needed is the condition of the structural elements that sustain the building loads. Many methods and varieties of test equipment are available for assessing the damage. Some tests can be made at the job site but others require studies of specimens in the laboratory. Although such studies may at times require sophisticated equipment much or all of the information can often be obtained with quite simple equipment or tools.

General survey

Surveys are useful for compiling whatever information is already known about the nature of the fire. They begin by drawing on information in fire department records and on reports from witnesses. That information includes the extent and duration of the fire, and the period when failures of members were observed.

Information about the type and amount of combustible materials can be used for estimating the prob-

TABLE I Estimating Temperatures Attained During Fires
(Adapted from Reference 1)

Factors for Use in Calculating Wood Load Below

Multiply weight of material per unit area by the factor indicated to obtain the equivalent wood load.

Material	Factor	Material	Factor	Material	Factor
Wood	1.0	Hay or straw	0.8	Cotton	0.9
Cellulose	1.0			Silk	1.2
Paper	0.9	Asphalt	2.1	Wool	1.2
		Coal tar	2.1		
Coal	1.8	Petroleum products	2.5	Nitrocellulose	0.5
Coke or charcoal	1.5				
Lignite	0.8	Animal or vegetable oil	2.1	Rubber	2.1
Peat	1.3	Fats and waxes	2.1		

Wood load		Equivalent fire test period (hours)	Probable temperature reached in fire atmosphere	
Pounds per square feet	Kilograms per square meter		Degrees F	Degrees C
12.5	61	1	1,700	927
12.5 - 25	61 - 122	2	1,850	1,010
25 - 50	122 - 244	4	2,000	1,093

TABLE II Conditions of Materials Useful for Estimating Temperature Attained Within a Structure During a Fire (Adapted from Reference 1)

Material	Typical Examples	Condition	Degrees F	Degrees C
Lead	Pluming lead; flashing; storage batteries; toys	Sharp edges rounded or drops formed	550 - 650	300 - 350
Zinc	Plumbing fixtures; flashing; galvanized surfaces	Drops formed	750	400
Aluminum and its alloys	Small machine parts; brackets; toilet fixtures; cooking utensils	Drops formed	1,200	650
Molded glass	Glass block; jars and bottles; tumblers; solid ornaments	Softened or adherent	1,300 - 1,400	700 - 750
		Rounded	1,400	750
		Thoroughly flowed	1,450	800
Sheet glass	Window glass; plate glass; reinforced glass	Rounded	1,450	800
		Thoroughly flowed	1,560	850
Silver	Jewelry; tableware; coins	Sharp edges rounded or drops formed	1,750	950
Brass	Door knobs; furniture knobs; locks; lamp fixtures; buckles	Sharp edges rounded or drops formed	1,650 - 1,850	900 - 1,000
Bronze	Window frames; art objects	Sharp edges rounded or drops formed	1,850	1,000
Copper	Electric wiring; coins	Sharp edges rounded or drops formed	2,000	1,100
Cast iron	Pipes; radiators; machine pedestals and housings	Drops formed	2,000 - 2,200	1,100 - 1,200

able temperatures reached within the building. If the building had contained, for example, not much other than about 10 pounds of vegetable oil per square foot of floor area, all of which was consumed in the fire, probable temperatures reached within the building can be calculated by using the information in Table 1. The amount of vegetable oil per square foot multiplied by the factor 2.1 (obtained from the top section of the table) gives a value of 21 pounds per square foot, the equivalent wood load to produce the same amount of heat. In the lower part of the table it can be seen that a wood load of 21 pounds per square foot, which falls in the range of 12.5 to 25 pounds, would supply the amount of heat consumed in a 2-hour fire test. If it is assumed that conditions at the actual fire were not significantly different from those in a standard fire test it would mean that the probable temperature reached in the fire atmosphere was 1,850 degrees F (found in the Fahrenheit column).

On-site survey

More reliable information about temperatures can be obtained during on-site surveys. One method is to note the condition of materials exposed to the fire (Table 2). Examinations of rubble might show that window glass had been melted and brass cupboard knobs had become rounded but that copper in electric wires had not been softened. These observations would point to temperatures that had certainly exceeded 1,560 degrees F (indicated by the glass) and had probably been higher than 1,850 degrees F (indicated by the brass) but not as high as the 2,000 degrees F required to melt copper.

Those temperatures, however, might not truly reflect the heat intensity reached in the concrete, which is likely to be less than in the air. Concrete color provides a broad, general guide of temperatures, whether the color represents the original surface or one resulting from spalling. Crazing, cracking,

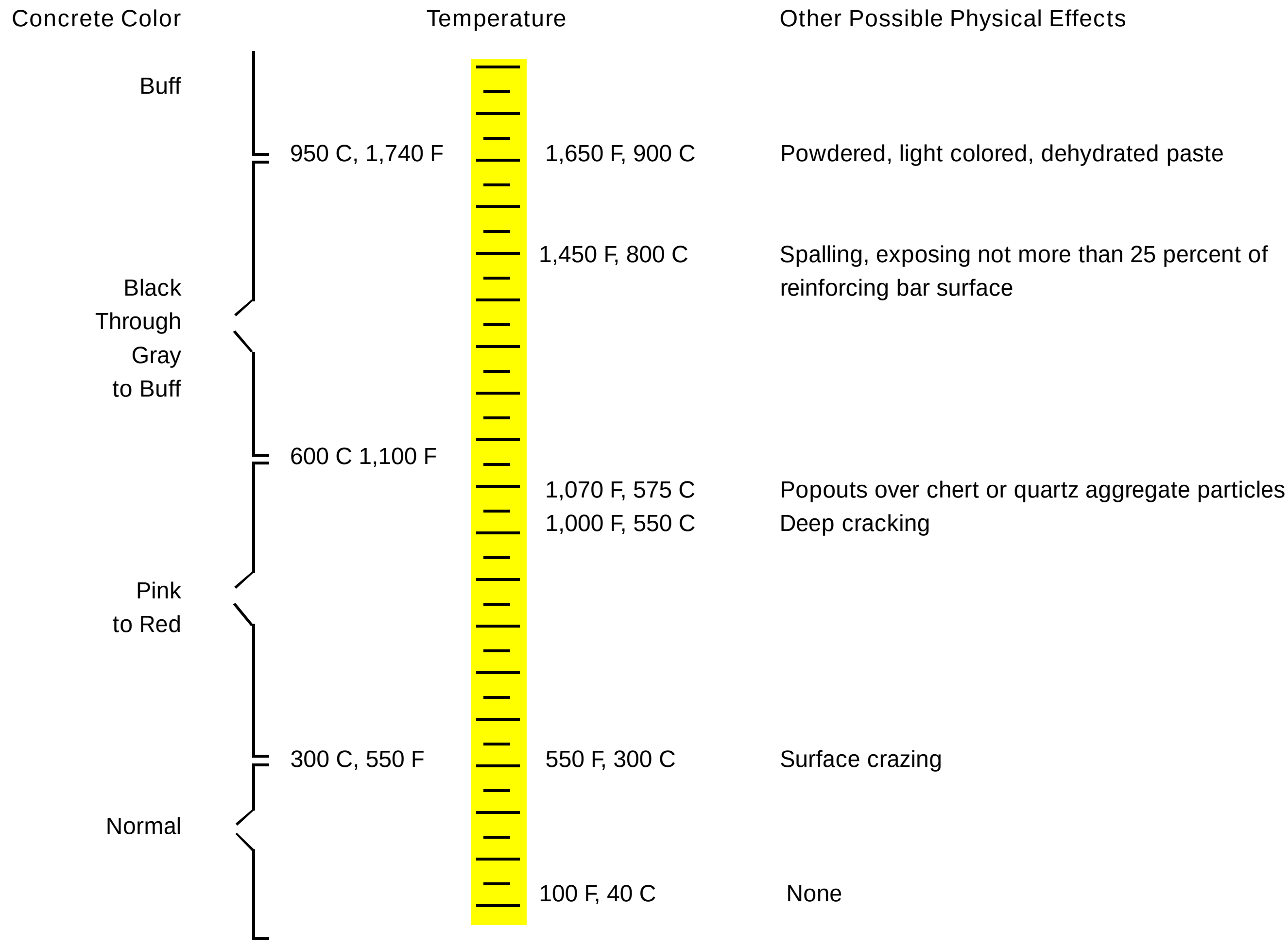


Fig. 1 Visual evidence of temperature to which concrete has been heated
(Adapted from References 1 and 2)

popouts caused by quartz or chert aggregate particles, spalling, and dehydration (crumbling and powdering of paste) are general indications of temperatures to which concrete has been exposed, as shown in Figure 1. Concrete temperatures will vary from one enclosed area to another and certainly from room to room.

The relationship of temperature and strength loss was discussed in the preceding paper of this series. As indicated there, surface temperatures usually are quite different from temperatures at different depths in the concrete, and thus estimates of strength of the internal concrete, when based on surface color, are speculative. If precise information on strength is needed other methods that will be discussed are required.

The amount and condition of exposed reinforcing bars or prestressing wires and strands are helpful indications for assessing damage. If the steel is draping or shows embrittled surfaces, serious concrete damage can be anticipated. It does not follow, however, that unexposed steel has been as seriously affected, if affected at all. The locations and lengths of exposed steel may be useful for reviews and recalculations of design requirements.

Distortions and cracking of structural members, as well as their locations, are useful for evaluating the efficacy of building units for sustaining loads. If cracks are located in critical places such as support areas, if deflections are observed anywhere, or if there are misalignments, the support capabilities may have been seriously impaired, whether support is carried by individual members or integrated members that constitute a support system.

Equipment commonly used at the site

Two very useful tools for examining field concrete are a hammer and chisel. Their resistance to impacts and their resonance when struck can reveal information about hardness, integrity, depth of damage, seriousness of cracking, and the condition of the steel.

Other useful tools and test instruments applicable in field studies or in removal of specimens for laboratory studies include: impact hammer, measuring tape, transit or theodolite, level, dial gages, field microscope, grinders, coring machine, wear test devices, steel hardness tester, soniscope, and load test devices.

TABLE III Methods for Details Appraisals of Condition of Fire-Damaged Concrete		
Condition of Property	Methods	Notes
Actual temperature reached in building	Examination of building contents	See Tables 1 and 2
Actual temperature reached in concrete	Visual examination of concrete, Petrographic, DTA, and metallurgical studies of steel.	See Fig. 1
Compressive strength	Tests on cores. Impact hammer studies. Penetration resistance. Soniscope studies.	
Soundness at highly stressed areas (upper side at center of beam; beam supports; anchorages for reinforcement near support; frame corners)	Hammer and chisel. Visual examination. Soniscope studies.	
Modulus of elasticity	Tests on cores. Soniscope studies.	
Dehydration of concrete	DTA. Petrographic analysis. Chemical analysis.	
Aggregate performance	Visual examination. Petrographic analysis.	
Spalling	Visual examination.Petrographic analysis.	
Cracking	Visual examination. Soniscope studies. Petrographic analysis.	
Surface hardness	Dorry hardness or other tests	
Abrasion resistance	Los Angeles abrasion test on concrete chips*	
Depth of damage	Visual examination for spalling, cracking. Color variation in cores. Chipping. Petrographic analysis.	See Fig. 1
Deformation of beams,	Visual examination. Straightedge and scale. Dial gages or theodolite if needed.	
Gross expansion	Visual examination. Checking of dimensions and levels.	
Differential thermal movements	Visual check of cores for loss of bond to steel. Color change in concrete next to steel.	
STEEL CONDITION Reinforcing steel, structural steel or prestressing steel	Physical tests. Metallurgical studies. Dimensional changes, displacement and distortion.	
Load carrying capacity	Load tests on structure	

* Of uncertain value for this purpose.

Methods for evaluating materials

By this time a good idea of the condition of the structure will have been achieved, and in a few cases enough information will be available to close the investigation. But often there will be questions that can be resolved only by detailed studies. Methods that can be used to obtain answers to questions regarding any of a number of properties of concrete or the condition of structural members are given in Table 3.

Cores can be used for evaluating strength and modulus of elasticity. Cores should be taken judiciously and from locations where their effect on strength will be minimal though they provide necessary data. Comparisons of these data should be made with data obtained from cores taken from areas that were not exposed to elevated temperatures. These comparisons provide the most reliable information on changes in concrete caused by the temperatures reached. Cores are also useful for giving incidental information about cracking in the interior of a member, the bond to reinforcing steel, and interior temperatures as revealed by color changes. Some of the information that can be obtained is shown in the schematic drawing of Figure 2.

The impact hammer is useful for estimating compressive strength, but only when a considerable number of measurements are made and compared to undamaged concrete of the same quality from within the same structure.

Determinations of pulse velocities, using a soniscope, provide indications of strength and modulus, and attenuated signals are indications of cracking. The soniscope is singularly the most effective nondestructive instrument for detecting cracks.

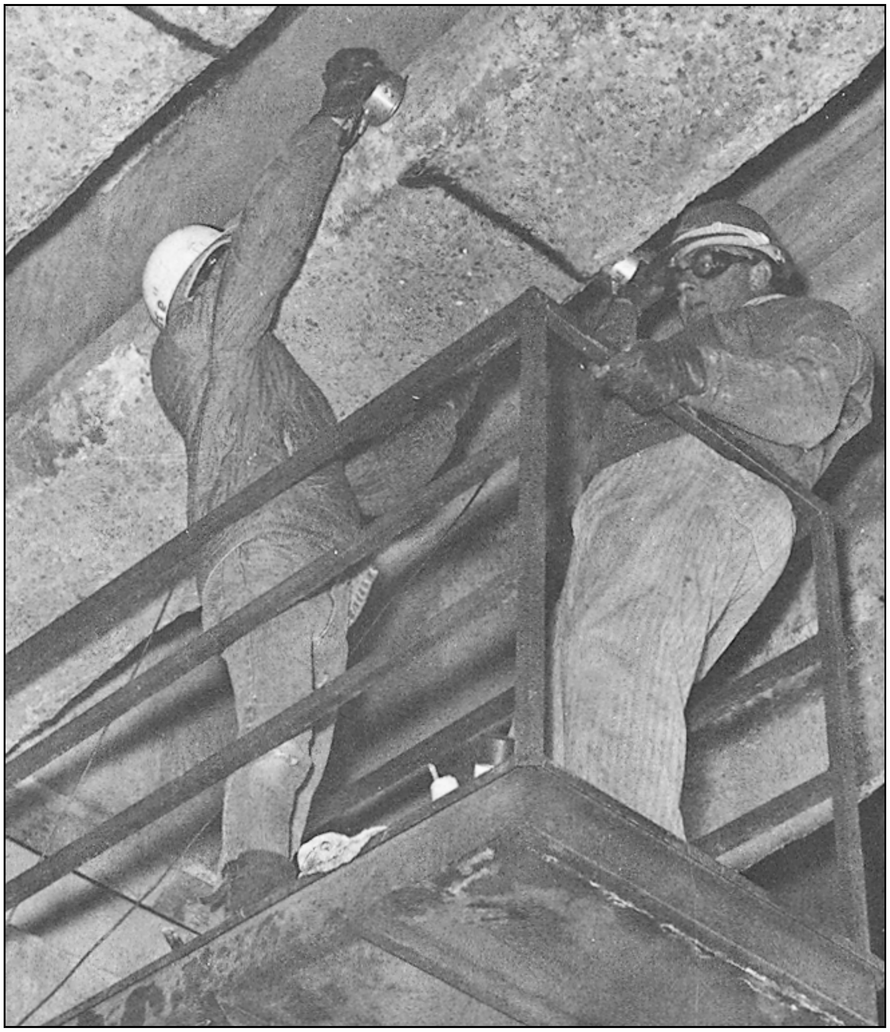
Cracking can also be studied visually in cores or fragments, but detailed information about cracking usually must be obtained by using petrographic methods. Suitably prepared specimens can reveal microcracks, their relationship to aggregate and steel, and their internal orientation.

The extent of concrete dehydration can be determined by using petrographic methods or by differential thermal analysis (DTA). Specimens for DTA studies should be carefully selected, preferably after the petrographic studies. The petrographic and DTA studies can be extended to assessment of the condition of the aggregate.

The hardness and abrasion resistance of surfaces, if they are of interest, can be measured by standard methods and compared to similar data from undamaged concrete in the structure.

Condition of steel

Often a major question in determining what structural repairs will be needed can be answered by determining the condition of steel. In floors and walls, exposed prestressing steel can be measured in place using metallurgical methods. If access to the steel is limited because of



Sonic signal being sent through fire-damaged concrete. Sender and receiver are being held tightly against the concrete; signal is recorded on a test instrument at floor or ground level.

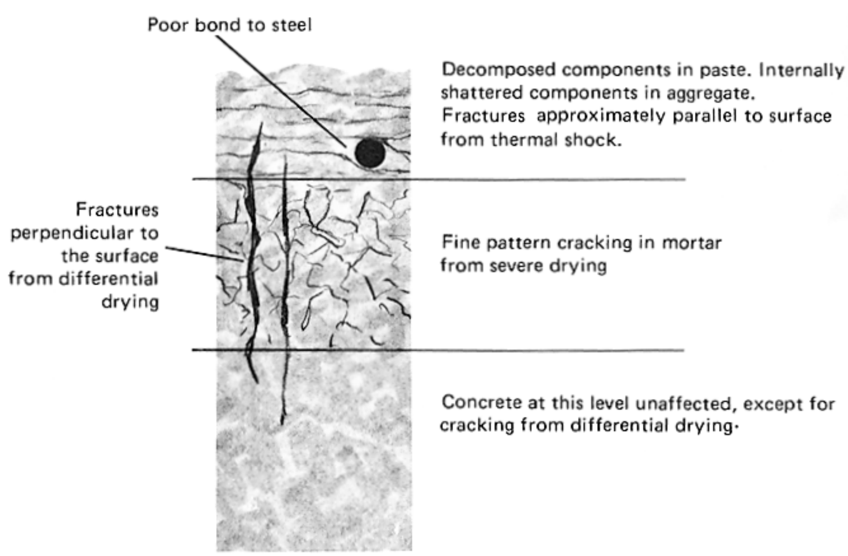


Fig. 2 Much information can be obtained by petrographic methods from cores taken at appropriate intervals. Data can be used to evaluate the extent, type and severity of damage and to estimate the temperatures to which the concrete was subjected.

height or structural conformation of the member, short lengths of steel can be removed for laboratory studies. A microhardness test can be used for determining the tensile strength of prestressing steel. This is particularly useful because it is rapid and accurate and requires only a small sample. It correlates well with tensile strength determinations. Tensile and other tests on prestressed or reinforcing steel samples are valuable because they give a direct measurement of the property of greatest interest. Studies of steel microstructure are useful for evaluating exposure temperatures and their effect on microstructure, and hence on physical properties.

Load tests

Although a compendium of indirect information about the structural capability of individual elements can be obtained, it may still become necessary, and is indeed frequently desirable, to determine the actual loading capacity of an integrated system of elements. For this an actual load test must be performed. That test can be made before reinstatement has been completed, afterward, or both. Tests completed prior to reinstatement will establish what repairs, if any, may be required; tests completed after reinstatement will indicate whether corrections have been adequate.

Usually, organizations experienced in job-site testing are best qualified for completing the load tests. They are well informed on the various methods that can be used, safety precautions that must be employed, and the interpretation of test data.

Serviceability

Aside from structural considerations, maintenance and safety of structurally noncritical conditions should be evaluated. For example, a concrete member may be structurally adequate, yet careful study of the surface region of the member may reveal incipient spalling or cracking that could result in eventu-

al dislodgment of concrete sections, small or large. Detailed studies, using petrographic methods, may thus be desirable.

Final evaluation

When all of the data are in and before repairs are undertaken there remain two determinations to be made: (1) what parts of the structure cannot be left in their present condition? and (2) should corrections be made by repair, replacement, or a combination of the two? These subjects will be discussed in the final paper of this series entitled "Reinstating Fire-Damaged Structures."

REFERENCES

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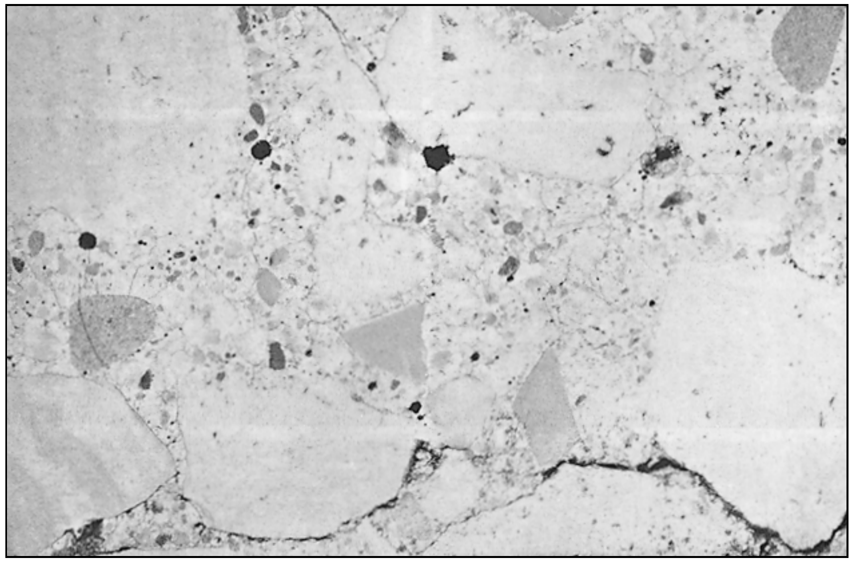
2. Smith, Peter, "Investigation of Repair of Damage to Concrete Caused by Formwork and Falsework Fire." ACI Journal, Proceedings V. 60, No. 11, November 1963, pp. 1535-1566.

Part I of this three-part article on fire damage to concrete structures appeared in CONCRETE CONSTRUCTION in March 1972. Part III will appear in May 1972



Photomicrograph shows a major crack, approximately parallel to a formed surface, that outlines an incipient spall caused by thermal shock. The intricate network of fine cracks in the mortar was caused by drying. More cracks were seen by direct microscopic viewing. Petrographic evidence showed temperatures had been high enough to dry the concrete but not to decompose components of the paste or aggregates.

Core removed for examination.

PUBLICATION#C720154