Façade Fire Tests: Towards an International Test Standard

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Abstract

Results of large-scale and bench-scale tests are reported on three EIFS (exterior insulation and finish systems) type façade assemblies. The large-scale tests were done according to a modified SP 105 test, while the bench-scale procedures followed CAN/ULC-S135. The tests were motivated by the current ISO deliberations to select an optimal international standard for testing façades against fire propagation hazards. The large-scale test showed distinct differences among the assemblies tested. However, certain difficulties were identified with the test, especially the smokiness of the fuel and the non-ideal dimensioning of the re-entrant corner. The bench-scale tests showed consistent results; such procedures may be useful for screening purposes.

Introduction

For small, low-rise buildings, few restrictions are normally placed on façade construction. Large or high-rise buildings, however, are expected not to lead to propagating fires over their façades. Two dramatic fires in Sao Paulo during the early 1970s[1,2] alerted the fire protection community to the very serious consequences that can result when fire does propagate over the façade of a high-rise building. The traditional point of view would be that façades "should be made of noncombustible materials." However, this is seen as out of date, since it is not based on a performance measure. Furthermore, it is known that, under certain circumstances, combustible material can be safely used in a façade assembly, provided the system involves adequate outer-layer protection. In other words, if actual performance of the entire system is satisfactory, combustibility is not a problem.

To measure adequate system performance, a large-scale test is needed since we are not yet able to predict the performance of such complex systems, such as façade assemblies, from bench-scale data alone. Until recently, each country had been developing its own tests in this area. In fact, more tests have been proposed than the number of countries making proposals. A 1988 survey[3] found that 10 countries had proposed 15 different façade tests.

Recently the International Organization for Standardization (ISO) undertook to develop an international standard for façade fire testing. Within ISO there are, in fact, two activities related to façade fires. The first concerns the fire endurance aspects of façades and is handled by its ISO TC92/SC2. The second concerns the fire propagation aspects of façades and is an active work item in ISO

Key words: cone calorimeter; EIFS; façades; heat release rate; ISO standards; large-scale tests.

TC92/SC1/WG7. The latter group has examined the 15 façade tests cited above, plus newer proposals from several countries. From the work of this group will emerge two test methods: a large-scale test and an intermediate-scale test. The intermediate-scale test is viewed as an economical screening test for the large-scale test. In the present work, we examine issues associated with the large-scale, not the intermediate-scale, strategy.

The ISO group has narrowed down the number of large-scale tests being considered to four. These are the tests proposed by Canada, Sweden, and Germany. Of interest is the fact that this ISO group of finalists does not include the large- and intermediate-scale tests developed by Southwest Research Institute (SwRI) and used by ICBO in the United States.[4] It is understood that the large SwRI test was viewed as excessively expensive and unnecessarily over-instrumented. The intermediate SwRI test was also seen as too complex, compared to the alternatives available.

The Canadian proposal is based on their existing CAN/ULC-S134 national standard.[5] The Canadian standard, developed by the National Research Council (NRC), provides for a specimen 5 meters wide by about 10.3 meters high. There is a single fire-room opening from which propane-fueled flames issue as from a window of a flashed-over room. Visual fire propagation and heat flux (at 3.5 meters above the window opening) are the primary variables used for assessing performance. Additional measurements are made with several thermocouples on and in the specimen.

The original Canadian standard involved a flat façade specimen. Observation of real fires has indicated, however, that the façade is more vulnerable when it has re-entrant corners—that is, when portions of the façade protrude from the main surface. Thus, more recently NRC studied the effect of such re-entrant corners.[6,7] One of the factors examined in the Canadian study was the spacing between the edge of the fire-room opening and the re-entrant corner. The study examined spacing distances of 0 and 0.5 meters, along with a straight façade (without re-entrant corners) of the kind envisioned in the original CAN/ULC-S134 test. The Canadian tests indicated a significant effect of the re-entrant corner, especially at the closer spacing.

The German façade test proposal is a somewhat simpler arrangement, comprising a façade wall 3 meters wide by 6 meters high. A re-entrant corner is formed using a 1.5-meter-wide wing wall. The wing wall is placed at zero separation from the fire opening. In the German test, the fire source is a 25 kg wood crib. Fire performance is judged with an array of thermocouples. The method was developed by I. Kotthoff of the Materialforschungs und Prüfungsanstalt für Bauwesen Leipzig. It is stated that many industrial tests have been conducted with this method, but no public release of example data has yet been made.

The present study is intended to illustrate the features and performance of the third method, the one originating in Sweden.

The Swedish Façade Test

The Swedish façade test has its origins in façade research done at Lund University.[8] Further development has been described in a study by the Swedish National Testing and Research Institute (SP).[9] The standard SP test method (SP 105) comprises a façade specimen 4.18 meters wide and 6 meters high. At the bottom edge of the specimen is a fire opening. The fire source is a pan filled with 60 liters of heptane. The test specimen is mounted on a lightweight concrete substrate structure. The geometric arrangement has two fictitious windows situated at the second and third stories. These windows are 50 millimeter indentations in the façade surface and are not actual openings. The centerpoint of the second-story window contains a heat flux meter. Additional instrumentation includes two thermocouples located at the top of the specimen, underneath a noncombustible eaves detail.

The standard SP 105 façade test did not include a re-entrant corner. For the present study, a re-entrant corner was created by mounting a wing wall section to represent a re-entrant corner. This wing wall was 1 meter wide (protrusion) and was mounted at the edge of the straight-façade segment—its face was located 0.59 meters from the edge of the fire opening. Figure 1 shows the test arrangement adopted. Using this modified SP 105 test configuration, three different specimens were tested, plus a control. The test specimens were commercial examples of EIFS (external insulation and finish system) façades used in Europe. Each of the three test specimens was identical, except for the type of insulation material.

The insulation material was fixed to the concrete substrate using a mineral-type plaster (ISPO Verbundmörtel Nr. 5900). The reinforcing net (ISPO Armierungsgewebe Nr. 8470) was troweled onto the surface of the insulation material at an application density of 3 kg m^{-2}, the same plaster as was used to adhere the insulation to the substrate. Finally, a surface plaster coat (ISPO Leichtputz K Nr. 5410) was sprayed onto the surface at a density of 3.0~3.5 kg m^{-2}. The total thickness of the surface plaster coat was approximately 8 millimeters.

The lay direction of the reinforcing net was horizontal, in six strips with a 10% overlap. The edges of the EIFS system were protected by a steel plate. At each of the fictitious windows, there was an elastic joint 10 millimeters wide, done up with a silicone compound. A similar elastic joint line was created between the specimen top and the steel eaves plate. The bottom edge of the specimen, the soffit of the fire opening, had the same plastered covering as the front surface of the façade. At the line where the soffit is brought back to the plane of the substrate, there was another elastic silicone joint. The particular façade system studied also used a PVC L-profile to join the EIFS to the substrate at this point. All insulation materials were 80 millimeters thick. The wing wall construction was similar to that of the main façade portion. The insulation materials are described in Table

1. The control test was a blank, intended to check the instrumentation and the fire source. No additional material was applied to the concrete façade-rig substrate for the control test.

The façade test rig is situated underneath a large-scale products calorimeter, allowing the heat release rate (HRR) and other properties, such as production of smoke and gases, to be quantified.

Performance According to SP 105 Test Criteria

The general character of the test performance can be seen from the HRR curves in Figure 2. The differences in HRR behavior among the test specimens are seen to be quite small; indeed, the differences between the test specimens and the con-

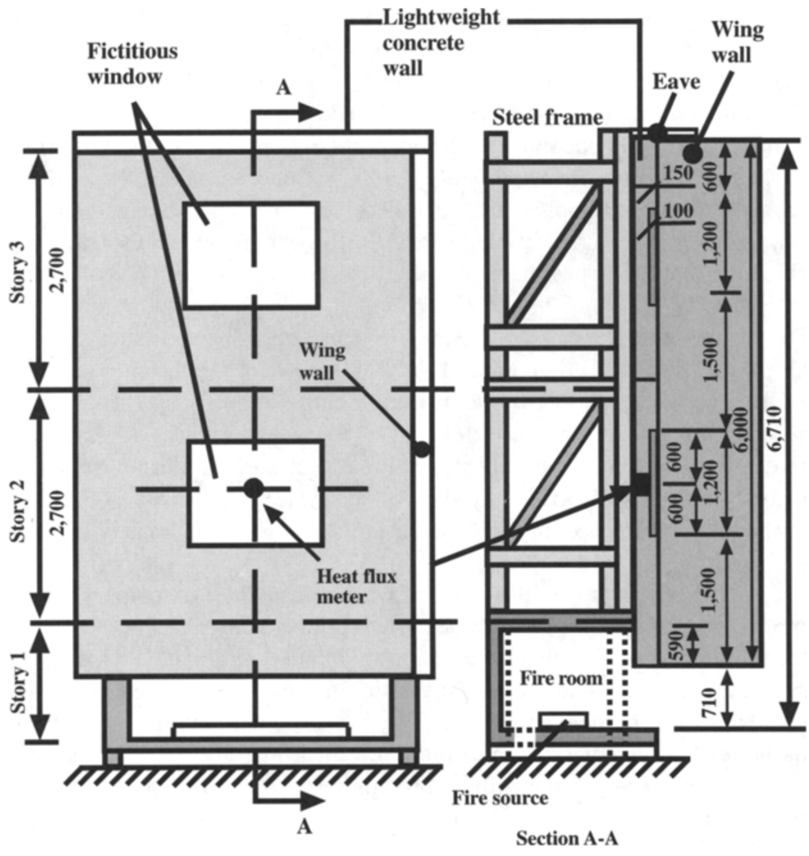

Figure 1. The modified SP 105 test arrangement used for the large-scale façade tests.

TABLE 1
The Tests Conducted and the Insulation Materials Used

Test	Material	Density [kg m^{-3}]
F0	blank	—
F1	rock wool	85
F2	EPS	16
F3	PUR	34

trol are not large. One can conclude from this that hazards associated with façade fires are primarily due to aspects other than the HRR itself. This is sensible: The effect of a façade fire on the occupants is secondary. Building occupants would rarely, if ever, be injured by flames or high temperatures of the façade. Instead, the hazard lies in the fact that the façade may act as a vehicle for fire spread, propagating fire into floors and rooms far away from the place of original ignition. It is these subsequent room fires (and the HRR associated with them) that will be the true occupant hazard.

Consequently, the criteria that have been proposed to assess the standard SP 105 façade test results comprise three variables:[9]

1. Flame spread and fire damage may not reach above the bottom of the second-story window.
2. Large pieces of the façade may not fall down during test.
3. The temperatures at the eaves may not exceed 500°C for more than 120 seconds, or 450°C for more than 600 seconds. For hospital occupancies the heat flux meter readings may not exceed 80 kW m^{-2}.

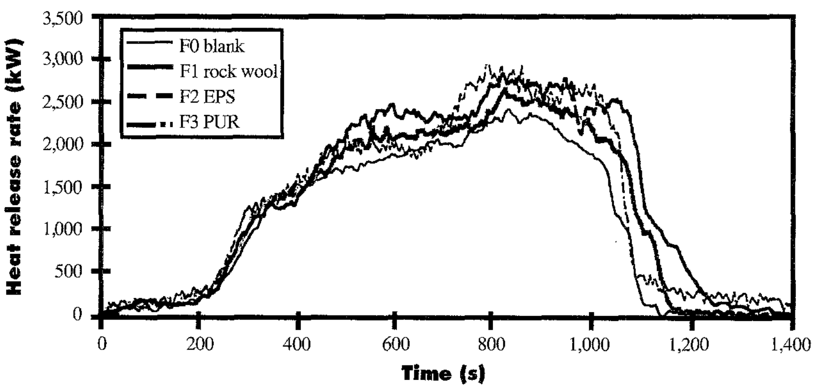

Figure 2. The HRR results for the tested façades.

TABLE 2
SP 105 Criteria and Measured Values

	Maximum Window Flux [kW m-2]	Maximum Eaves Temp. [°C]	Maximum Damage
Criterion	*80*	*500 (for 120 s); 450 (for 600 s)*	*bottom of 2nd story window*
F0—blank	43	260	none
F1—rock wool	42	292	none
F2—EPS	26	382	top of 3rd story window
F3—PUR	60	299	bottom of 3rd story window

The performance of the test specimens against these criteria is given in Table 2. It can be seen that none of the test specimens came close to exceeding the maximum values for eaves temperature or for window heat flux. Where the specimens did differ is in the amount of damage. This is summarized in Table 2 and further details are provided in Figure 3. Specimens F2 and F3 also suffered fall-off of large pieces of the plaster coat, in addition to burning and insulation material damage.

The damage pattern is interesting to explore more closely. Two observations can be made:

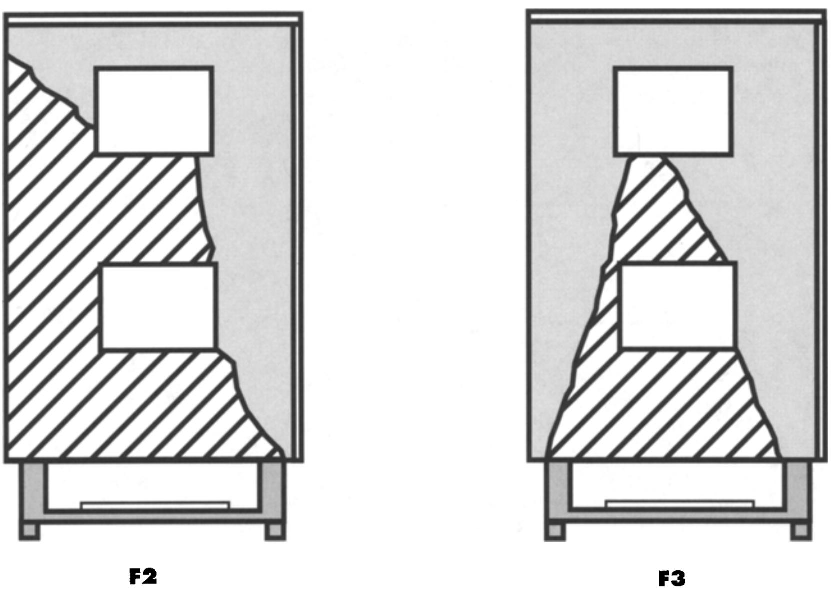

Figure 3. The damaged areas for specimens F2 and F3 (specimen F1 did not show post-test damage.

1. Even in cases where significant façade damage occurred, there was no damage on the wing wall.

2. The damage to the façade was not symmetrical around the vertical centerline. Instead, it tended to be greater on the left side, away from the wing wall.

The lack of damage to the wing wall can be explained in the following way. The greatest fire impact on the façade can be expected from direct flames, rather than from thermal radiation. Direct flame impact to the re-entrant corner of a building can be expected when flames are attached to the surface. Flames do not tend to attach to a surface unless they are quite close to it. The presence of a large (> 0.5 meters) space between the fire opening and the wing wall surface in the present rig represented much less than worst-case conditions. In real life, however, worst-case conditions must be considered when buildings are designed with window openings directly abutting a perpendicular wall—that is, within a re-entrant corner.

After the test series was completed, a detailed investigation of air flow patterns in the test hall was made. This showed that there was a very slight imbalance of air supply to the vicinity of the test rig, which accounted for the off-center damage pattern. With the given wing wall spacing, it is estimated that the façade damage patterns would have been nearly centered had a fully symmetrical air flow been achieved. For damage to have occurred predominantly on the right

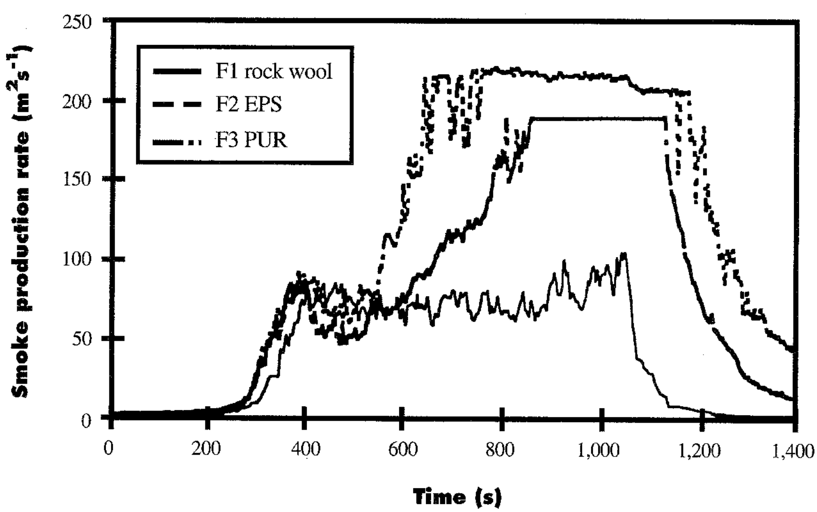

Figure 4. Smoke production rates measured in the exhaust duct.

side, a much smaller spacing would have been required between the fire opening and the wing wall.

Smoke Production

Since the test rig is underneath a large HRR calorimeter, it is possible to record additional aspects of specimen behavior. For the present tests, a laser photometer, constructed like the laser photometer used with the cone calorimeter,[10] was available in the exhaust duct. The data are provided in Figure 4. Results for the blank test, F0, are not available, since the photometer was still being installed at the time test F0 was conducted. The measurements quantify the visual observations that the heptane fuel used is an exceedingly smoky fire source. Indeed, observations of the specimen surface during testing were largely precluded due to the thick, black smoke the fire source generated.

Visually, it was also very difficult during testing to distinguish between the smoke production tendencies of the test specimens. However, the laser photometer results however indicate that there was a significant difference among the specimens in their smoke production tendencies. Specimen F1 did not ignite and burn. Consequently, its SPR record indicates an essentially steady-state value, due solely to the heptane source. Specimens F2 and F3 can be seen from the smoke record to start producing additional smoke contributions at around 600 seconds. By 700~800 seconds, the photometer system became overwhelmed by the smoke produced, and the curves are subsequently seen as topped-out. The F2 and F3 HRR curves have returned to zero at around 1,200 seconds, while the SPR curves are still tailing down, indicating that the smoke production also overwhelmed the photometer purging system and that some smoke deposition had occurred on the optics.

Bench-Scale Tests

When façades show fire failure, the failure mode is usually quite complex. It may involve delamination, joint failures, and fire propagation internally, parallel to the façade surface. Fire modeling is not yet advanced enough to be able to predict such failures. Thus, the role of bench-scale data, which would normally be considered as input into a fire model, is not clear in the case of façades.

In view of this, most countries have simply focused on large-scale test development or, in a few cases, development of intermediate-scale tests. One exception is Canada. There, a test bench-scale test method has been proposed as part of the assessment procedure for façade fire performance. This method is a variation of the cone calorimeter[11] (ISO 5660; ASTM E 1354) test method.

The Canadian method, CAN/ULC-S135,[12] differs in that it prescribes the use of an insulated edge frame around the test specimen, specifies a specimen irradiance of 50 kW m^{-2}, and limits test time to 900 seconds. The Canadian test is not intended solely for façades. It is being considered as a general-purpose

TABLE 3
Bench-Scale Test Results According to CAN/ULC-S135

Property	Variable	F1 rock wool	F2 EPS	F3 PUR
Ignition time [s]	t_{ign}	—	248	176
Flameout [s]	$t_{flameout}$	—	578	687
Peak HRR [kW m^{-2}]	$\dot{q}''_{pk}$	13	154	71
Avg HRR, 60 s [kW m^{-2}]	$\dot{q}''_{60}$	2	43	39
Avg HRR, 180 s [kW m^{-2}]	$\dot{q}''_{180}$	4	78	52
Avg HRR, 300 s [kW m^{-2}]	$\dot{q}''_{300}$	6	71	55
Total heat produced [MJ m^{-2}]	THR	4.0	27.9	25
Peak SPR [m^2 s^{-1}]	SPR_{max}	*	0.071	0.025
Average SPR [m^2 s^{-1}]	SPR_{avg}	*	0.015	0.009
Total smoke produced [m^2]	TSP	0.41	9.54	6.59
Sample mass before test [g]	$Mass_o$	127.5	69.2	91. 5
Avg mass loss rate [g m^{-2} s^{-1}]	MLR_{avg}	0.56	1.31	1.59
Total mass loss [g]	TML	5.0	8.5	11.5
Eff. heat of comb [MJ kg^{-1}]	ΔH_c	6.9	29.2	19.5
Spec. extinction area [m^2 kg^{-1}]	SEA_{avg}	83	1135	575
Peak conc. HCN [ppm]		3	*	13
Peak conc. HCl [ppm]		*	*	18
Peak conc. HBr [ppm]		*	*	*
Peak conc. CO [ppm]		22	69	34
Prod. CO [mg]		106	340	334
Prod. CO_2 [g]		2.55	19.93	20.51
Prod. HCl [mg]		*	*	112
Prod. HCN [mg]		27	*	138
Prod. HBr [mg]		*	*	*
Prod. NO [mg]		53	11	104
Prod. NO_2 [mg]		19	14	*
Prod. TUHC [mg]		168	228	176
Cons. O_2 [g]		2.16	18.05	16.84
Yield CO [g kg^{-1}]		21	40	29
Yield CO_2 [kg kg^{-1}]		0.51	2.35	1.74
Yield HCl [g kg^{-1}]		*	*	9
Yield HCN [g kg^{-1}]		5	*	12
Yield HBr [g kg^{-1}]		*	*	*
Yield NO [g kg^{-1}]		11	1	9
Yield NO_2 [g kg^{-1}]		4	2	*
Yield TUHC [g kg^{-1}]		33	27	15

* measured values were at or below the detection limit of the instrument.

replacement for the older, prescriptive building code concept of noncombustibility. However, its development was especially focused on making it useful forfaçade testing.[13] For example, the insulated frame was designed to allow composites of plaster cover/foam interior to be tested as a realistic sandwich assembly. Because of the specific coverage of the CAN/ULC-S135 test of façade systems, the present test specimens were also tested using this bench-scale test. The results are given in Table 3. The data given represent the average from three test runs except for the chemical species measurements, which were done during a single run only. Additional tests (not shown) were also made using the standard ASTM E1354 procedures. Those results were not greatly different for F1 and F3. Specimen F2, however, exhibited a peak HRR value of 260 kW m^{-2} using the standard test procedure. This indicates that the CAN/ULC-S135 procedure is effective in allowing low-flammability surface layers to protect higher-flammability core material.

Using the peak HRR from the bench-scale test and the SP 105 criteria for the large-scale test, the ranking of the products according to CAN/ULC-S135 is the same as it is according to the large-scale test, from best to worst: F1 (rock wool), F3 (PUR), and F2 (EPS). Furthermore, the bench-scale values also reflect that F1 performed much better than F3, while F3 performed only slightly better than F2.

This sort of observation should not be considered a firm or quantitative conclusion, however. No actual correlation can be made on the basis of only three data points. Furthermore, correlations should not be relied upon when it is known that essential features of fire physics are not being represented. In the present case, it is clear that the CAN/ULC-S135 test does not examine joints, edges, and other points of potential weakness in the full-scale system.

Summary and Conclusions

ISO is currently deliberating the desired features of a large-scale façade fire test. The purpose of such a test is to examine the propensity of a façade system to propagate fire to floors above the fire floor. The ISO selection has narrowed down to three methods, as proposed by Canada, Sweden, and Germany. The experimental work in the present study was intended to explore the performance of the Swedish test proposal.

The proposed Swedish test rig uses a heptane pool fire in the fire room, two simulated windows, and a wing wall located slightly more than 0.5 meters from the edge of the fire opening.

In the present study, three façade systems of the EIFS type were examined. These were identical except for the insulation material, which was rock wool, EPS, and polyurethane foam, respectively. The test systems showed distinct differences. F1 (rock wool) would have passed the criteria proposed by Sweden (but not formally being considered by ISO). Specimens F2 (EPS) and F3 (PUR) would not. Of the latter, F3 showed a better performance than F2. Since the assemblies all used identical construction techniques, plaster coating, and mesh reinforcement, no conclusions are drawn about the ability of the test method to properly assess variations in these EIFS features.

The Swedish test simulates façade fires in a reasonably realistic manner. However, two difficulties were identified with the method: the smokiness of the heptane fuel makes specimen observations difficult; and the wing wall placement was too far away from the edge of the window opening to adequately represent the kind of fire impact on a re-entrant façade corner that might be expected in real life conditions. Finally, it was not seen from these tests that the use of simulated windows at the second and third stories in the method contributed useful information towards assessing the test products. It might be better to either omit this feature or to provide real window details there.

Bench-scale tests on the same systems were made using the CAN/ULC-S135 test. These showed generally similar performance trends, as did the large-scale tests. However, due to the small number of products evaluated and because the bench-scale method does not simulate certain features of the full-scale assembly, which can be important in determining fire performance, reliance on bench-scale data cannot be recommended at this time.

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