NASA Technical Memorandum 84337

(NASA-TM-84337) FIRE RESISTANT FILMS FOR AIRCRAFT APPLICATIONS (NASA) 36 p
HC A03/MF A01
CSCL 01C
N83-22320
Unclas
G3/23 03380

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March 1983

National Aeronautics and
Space Administration

NASA Technical Memorandum 84337

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FIRE RESISTANT FILMS FOR AIRCRAFT APPLICATIONS

ABSTRACT: Alternative sandwich-panel decorative films were investigated as replacements for the polyvinyl fluoride currently used in aircraft interiors. Candidate films were studied for flammability, smoke emission, toxic gas emission, flame spread, and suitability as a printing surface for the decorative acrylic ink system. Several of the candidate films tested were flame-modified polyvinyl fluoride, polyvinylidene fluoride, polyimide, polyamide, polysulfone, polyphenylsulfone, polyethersulfone, polybenzimidazole, polycarbonate, polyparabanic acid, polyphosphazene, polyetheretherketone, and polyester.

The films were evaluated as pure films only, films silk-screened with an acrylic ink, and films adhered to a phenolic fiberglass substrate. Films which exhibited the highest fire-resistant properties included PEEK polyetheretherketone, Aramid polyamide, and ISO-BPE polyester.

INTRODUCTION

Sandwich panels are used extensively in wide-body aircraft interiors because of their desirable stiffness-to-weight ratio. For example, a typical wide-body aircraft has over 102 m^2 of sidewall, 214 m^2 of ceiling, 474 m^2 of stowage bin, and 111 m^2 of lavatory and galley sandwich panels.

These panels are decorated in most cases with a polyvinyl fluoride (PVF) film which is the carrier for a screen-printed ink resin and which is covered with a second, thinner transparent PVF film. Because the surface of such film in the interior of an aircraft is large, it is important to evaluate alternative films for properties that would reduce the risks of fire initiation and propagation, and smoke and toxic gas evolution of these films, and thus of the whole panel.

DESCRIPTION OF TEST METHODS*

A broad range of flammability, thermochemical, and mechanical tests were conducted to fully characterize the candidate-film materials and to select the appropriate test methods to be used in future programs. The extensive laboratory testing in the flammability area was necessary because the implications of laboratory-scale test results are not fully understood; that is, the correlation between small-scale and large-scale tests has not been established. Five basic properties of the materials were measured: (1) propensity to burn, (2) smoke emission, (3) heat release, (4) toxic gas emission, and (5) flame propagation. In some cases, more than one test apparatus was used to measure the same property, thus allowing a comparison of test methods.

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*The use of trade names of manufacturers in this report does not constitute an official endorsement of such products, either expressed or implied, by the National Aeronautics and Space Administration.

Propensity to Burn

The propensity to burn was measured using the standard Bunsen burner exposure test [1] and the limiting oxygen index (LOI) test [2]. The vertical 60-sec ignition Bunsen burner test was chosen because it is the standard flammability test required by the FAA for testing wide-cabin interior materials. This test measures burn length and the time to extinguishment after the igniting flame is removed. The LOI test was run to determine the propensity of the materials to burn. This test exposes the specimen to an open flame in a controlled nitrogen/oxygen atmosphere and gives a ranking index that may be used to compare materials. A higher amount of O_2 necessary to sustain burning indicates a greater resistance to burning; an index rating of 100 indicates that the material would only burn in an atmosphere of 100% O_2. The ratio of N_2 to O_2 is regulated; thus, concentrations of up to 100% O_2 can be obtained.

Smoke Emission

The smoke-emission characteristics of the candidate materials were determined using the technique of smoke accumulation in an enclosure and by testing the materials in the National Bureau of Standards (NBS) smoke chamber [3]. The apparatus was operated over a range of incident heat fluxes, 1.5 to 5.0 W/cm^2, to determine the response of the films and laminates to various fire environments.

Heat Release

Heat-release characteristics of the candidate materials were determined from the Ohio State University (OSU) release-rate apparatus using the technique of heat release in an exposed airstream. The apparatus was operated at an incident heat flux of 2.5 W/cm^2 to determine the response of materials to this fire environment.

Toxic Gas Emission

Toxic gas emissions were measured in two separate tests: gas accumulation in the NBS chamber and a quantitative measure of gases from pyrolysis-tube decomposition. The NBS-chamber exposure represents an open-fire condition where only partial (or surface) burning takes place. The pyrolysis-tube exposure represents complete decomposition of the sample, since the specimen is exposed to a 600°C heat source. Samples were taken in the NBS chamber using calorimetric tubes (for HCN and NO_x), NaOH absorber solutions (for halide gases), and on-line gas detectors (for CO and CO_2). The NaOH solutions were analyzed using specific ion electrodes. Samples were taken of the pyrolysis-tube effluent using NaOH absorber solutions. The difference between the two sample techniques was that the gases from the NBS chamber were taken as a grab sample and results were expressed as a concentration (parts per million) of the gas in the accumulation chamber, whereas gases from the pyrolysis tube were absorbed during the entire test and results were expressed as a total yield (i.e, milligrams of gas per gram of sample).

Flame Propagation

The flame-propagation properties were measured on the ASTM E162 flame-spread apparatus [4], which measures the surface flammability characteristics of materials. This method of measuring material surface flammability uses a radiant heat source in front of which an inclined specimen of the material is placed. The orientation of the specimen is such that ignition is forced near its upper edge and the flame front progresses downward. A flame-spread index (I_s) was calculated by combining two factors: one factor derived from the rate of progress of the flame front (ignition properties) and another factor relating to the rate of heat liberation by the material being tested.

Thermochemical Tests

Both differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) thermochemical tests were run to determine (1) the decomposition rates of the films, (2) the exotherm/endotherm of the materials as they were decomposing, and (3) their weight loss. The materials with high exotherms were considered undesirable because of their potential contribution to a fire. Materials with a high weight loss at temperatures below 260°C were undesirable because the gases given off at these low temperatures would contribute ignitable fuel to a fire.

Mechanical Tests

Mechanical-property tests were run on the candidate films to determine their bond strength, wear resistance, and tensile properties. Bond strengths were measured by determining the peel strength between top films and substrate films, and between substrate films and fiberglass-preimpregnated films. Resistance to wear was measured using the Taber abraser to determine the number of cycles required to penetrate the film laminate. Tensile properties were measured by calculating the elongation, tensile strength, and breaking factor of the materials.

Additional Tests

Tests were run on the decorative films to determine their resistance to staining and to ultraviolet (UV) light degradation, and their ink adhesion/flexibility, dimensional stability, and texture attainability. All of these tests relate to the aesthetics of the decorative film — a very important consideration. Color stability was measured by monitoring color shifts of the films after exposure to UV light. Ink adhesion/flexibility was measured by screen-printing the candidates with the currently used acrylic ink system and determining the bonding, flexibility, and coverage characteristics. Dimensional stability was measured by calculating the change in size of a specimen following its exposure to a temperature of approximately 132°C for approximately 10 min.

The selection criteria and test methods used for evaluating the films are shown in Tables 1 and 2.

DESCRIPTION OF MATERIALS

New materials were selected to test their fire resistance through burning more slowly, emitting less smoke, emitting less toxic gas, and/or retarding the flame spread during a fire exposure. The candidate decorative films tested are shown in Table 3 and included polyvinylidene fluoride, PVF (FM Tedlar), three polyesters (ISO-BPE, Melinex 334, and Permacare IV 2693), polyphosphazene, polybenzimidazole, two polyimides (Kapton and DAPI-BPTA), polyparabanic acid, acrylic, polycarbonate, polyethersulfone, polysulfone, polyphenylsulfone, ionomer, two polyamides (Nomex and Aramid Film A), and polyetheretherketone. Some of these films were color pigmented, others were naturally colored, and still others were clear. Some were tested as candidates for a top protective film, some for a substrate, and others for both applications. However, all were compared to the baseline PVF film (No. 1) used by aircraft manufacturers today. During the evaluation testing, films were first considered individually and then in combination (i.e., top film and substrate film laminated together). Testing of candidate films in conjunction with a sandwich-panel substrate was unnecessary; instead, combinations (film laminates) were evaluated bonded to a three-ply phenolic/fiberglass composite.

Baseline System

Two basic types of decorative sandwich panels are currently in use by aircraft companies. The first type consists of a precured blank panel onto which is bonded a decorative polyvinyl chloride outer layer. The materials used in the sandwich skins are normally flame-retarded (FR) epoxy/fiberglass (e.g., halogenated). The honeycomb core was phenolic/Kraft paper before 1970, but has since been changed to phenolic/polyamide paper. The second type of decorative sandwich panel considered for this study consists of an integral decorative skin that replaces the polyvinyl chloride and also forms the structural member of the sandwich panel. The decorative layer in this type of construction is printed or silk-screened PVF. Like the material used in the first type, the face sheets of this type of panel are FR epoxy/fiberglass and the honeycomb core is phenolic/polyamide. The epoxy/fiberglass-face-sheet and phenolic/polyamide-honeycomb-core portions of the sandwich panel were studied previously [5], for flammability, smoke, and toxicity comparisons. Therefore, only the phenolic-fiberglass decorative layer was considered in this study.

RESULTS AND DISCUSSION

The films were evaluated in a series of tests documented in Tables 1 and 2. The first screening involved the evaluation of neat films only; the second screening involved the evaluation of film laminates consisting of a top film of clear 0.025-mm PVF bonded to a substrate 0.051-mm candidate film which had been screen-printed with acrylic ink; and the third screening involved film laminates consisting of (1) 0.025-mm PVF bonded to a 0.051-mm candidate film, (2) 0.025-mm PVF bonded to a 0.051-mm candidate film bonded to a three-ply phenolic fiberglass with an adhesive, and (3) 0.025-mm PVF bonded to a 0.051-mm candidate film bonded to a single-ply phenolic fiberglass with no adhesive.

First Screening

Individual films were tested for LOI, smoke emission, toxicity, tensile strength, and elongation. The LOI data for the films are shown in Figure 1. LOI values ranged from 19.0 for polymethylpentene (Film No. 14) to 43.1 for Kapton polyimide (Film No. 4). Currently used PVFs have LOI values below 30; therefore those materials exhibiting values above 30 would possess a lesser tendency to burn than the currently used PVFs. While these LOI data are not conclusions in themselves, they do indicate a general ranking of the films. These data, combined with other flammability properties, can give an overall ranking of the films.

The smoke-emission characteristics of the films were measured by testing individual films in the NBS smoke chamber, which is a closed, noncirculating accumulation compartment. The apparatus was operated at 2.5 W/cm^2 for 4.0 min in a flaming mode (see Figure 2). In general, polyphosphazene, polyesters, and acrylics produced more smoke than most of the other films. This is probably due to the presence of fire-retardant additives and/or inherent properties of the polymers. Polyimides, polyamides, polybenzimidazole, polyparabanic acids, polycarbonates; polysulfones, and ionomers produced less smoke than the currently used PVFs. These materials are generally more thermally stable than PVF. The polyvinylidene fluorides produced about the same amount of smoke as the currently used PVFs.

Toxic gas evolution was measured by sampling the gases collected in the NBS smoke chamber during the smoke-emission test. Figure 3 shows the CO and HF evolution from the films. Gas samples tested in the NBS chamber gave off only small amounts of HCN, NO_X, and HCl, and a relatively small amount of CO. As expected, the baseline PVF evolved the most HF. FM PVF and polyvinylidene fluoride showed lower HF evolution, when compared with the baseline PVF. The absence of toxic gas emission data on many of the films is due to the unavailability of material and/or no measurement being made. For instance, HF evolution was not measured for polycarbonate since it contains no HF-producing material.

Mechanical strengths of the candidate films were determined by measuring the tensile properties in the longitudinal direction. Measurements were made at failure and at yield. Figure 4 represents the ultimate-elongation test results. Elongation was determined to check the ability of the films to be textured and formed to complex shapes. Although no precise elongation and tensile-strength requirements can be established, it is desirable to have a minimum of 20 to 30% elongation and approximately the same tensile strength as the currently used PVF.

It can be seen in Figure 4 that polyetheretherketone (Film No. 24) and ionomer (Film No. 16) have approximately the same ultimate elongation as the baseline PVF (Film No. 1), making them excellent candidates for decorative films.

Second Screening

The second screening involved the testing of the 0.025-mm PVF bonded to the candidate films which had been screen-printed with ink. Ink-compatibility, adhesion and flexibility, texture-attainability, UV-stability, and shrinkage tests were run on the candidate films remaining after completion of the first flammability screening. Ink compatibility was determined by silk-screen printing of a white acrylic ink on the substrate film and subsequently observing for any detrimental effects, such as the ability of the ink to cover the substrate film's color. Adhesion and flexibility were determined on the screen-printed samples by tightly rolling the samples around a 13-mm wooden dowel with the screen-printed face positioned inward. This was repeated 10 times and observations were made for cracking, flaking, and separation of the ink film.

Shrinkage was determined by exposing 15.2- by 15.2-cm samples to a temperature of 132°C for 10 min in a circulating-air oven. The samples were measured in the transverse direction both before and after the 10-min exposure.

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Only the ionomer (Film No. 16) was dropped from further evaluation based on shrinkage test results. Ultraviolet stability was determined by the procedure described in ASTM G27-70 [6]. The stability of the test specimens, which measured 6.4 by 15.2 cm, was determined at the end of a 25-hr UV-exposure period. Films which were unstable under UV exposure included Aramid polyamide (Film No. 11), polyethersulfone (Film No. 13), and polyvinylidene fluoride (Film No. 17). These materials either discolored or lost their mechanical properties after the UV exposure.

Final Testing

Final testing was conducted on three types of laminates, as shown in Table 2, which represent various stages of construction of a typical sandwich panel (Figure 5). The film laminates which remained as candidates after the first and second screening are shown in Table 4. These film laminates were tested for LOI, HF evolution, peel and tensile strength, and ultimate elongation. The LOI results are shown in Figure 6. The LOI values ranged from 24.2 for the ISO-BPE polyester film laminate (Film No. 6) to 53.9 for the polyvinylidene fluoride film laminate (Film No. 17). Laminates of Fluorex HT-1 exhibited the highest LOI of 52, and the others fell into a range of about 24 to 35. The film laminates were pyrolized in a round tube in a furnace, and the HF evolution was determined. As expected, the highest HF evolution was from the baseline PVF (Film No. 1) followed by the FM PVF (Film No. 2) and polyvinylidene fluoride. Complete test results are shown in Figure 7. Peel-strength (top film-substrate film interface) tests were performed and the results are shown in Figure 8. The peel strength was determined to evaluate the bond strengths between the top and substrate films. The ISO-BPE polyester film showed the lowest peel strength, and the PEEK polyetheretherketone film (Film No. 24) showed comparable peel and tensile properties to the baseline PVF. The yield strength and the ultimate elongation of the film laminates were determined and are shown in Figure 9. It can be seen that the PEEK polyetheretherketone film has equivalent ultimate elongation and higher yield strength than the baseline PVF film. The ISO-BPE polyester film was extremely brittle and therefore was not suitable for complex panel shapes. Specimens consisting of a film laminate and a three-ply phenolic/fiberglass composite bonded together with a pressure-sensitive silicone adhesive were tested. The flame-spread characteristics of the films were measured to determine their contribution to the surface fire propagation properties of a sandwich panel and the test results are shown in Figure 10. All of the laminates with fluorine-containing substrate films exhibited approximately equal flame-spread characteristics, whereas the ISO-BPE polyester (Film No. 6) showed increased I_s values compared with the others. The baseline PVF had a lower I_s value because the film peeled away from the front surface of the flame, thus exposing the phenolic/fiberglass substrate, which has a lower flame-spread value. The smoke emission of the same laminates is shown in Figure 11, and the toxic gas emission of these laminates is shown in Figure 12. As expected, high HF evolution is shown in the FM PVF and polyvinylidene fluoride laminates.

The heat-release data for the laminates is shown in Figure 13. Since the mass of the films was insignificant compared with the mass of the phenolic fiberglass, small differences were observed between the laminates containing the films, and the significance of the data is questionable.

Similar flammability tests were conducted with the films bonded to a single ply of phenolic fiberglass. The flame-spread data for these laminates

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are shown in Figure 14. The lowest flame spread was exhibited by the PEEK polyetheretherketone laminate (Film No. 24) and the highest flame spread was exhibited by the ISO-BPE polyester laminate (Film No. 6). In the case of the baseline PVF (Film No. 1), as soon as the flame begins, the film burns and shrinks away from the flame front.

The vertical FAA flammability test was conducted on these laminates and the test results are shown in Figure 15. All of the samples were acceptable according to FAA standards.

The smoke emission of these laminates was determined at three heat fluxes: 1.5 W/cm^2, 2.5 W/cm^2 and 5.0 W/cm^2. The test results are shown in Figure 16. The CO and HF evolutions are also shown as a function of heat flux in Figures 17 and 18. The PEEK polyetheretherketone laminate (Film No. 24) had the lowest smoke evolution at all heat-flux ranges.

CONCLUSIONS

The propensity to burn and the toxic gas emission, especially HF, of panels can be significantly lowered by using polyetheretherketone as a substrate film suitable for screen printing ink. The relative ranking of the films based on these laboratory studies is shown in Table 5. Potential problems such as clarity, gelation spots in the film, and suitable width will have to be resolved before this film can be developed to its full potential. The Aramid polyamide film had good fire-resistant properties but had low elongation and was UV-unstable. The ISO-BPE polyester also had a very low elongation and was extremely brittle. All of the fluorinated films (baseline PVF, FM PVF, and polyvinylidene fluoride) exhibited very high HF evolution.

ACKNOWLEDGMENTS

The author wishes to acknowledge the Boeing Commercial Airplane Company for conducting many of the tests described in this paper. Complete test data are given in Reference 7.

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3. T. G. Lee, "Interlaboratory Evaluation of Smoke Density Chamber," NBS Technical Note No. 708, 1971.

4. ASTM E 162, Standard Test Method for "Surface Flammability of Materials Using a Radiant Heat Energy Source," American Society of Testing Materials, Washington, D.C.

5. R. A. Anderson, D. B. Arnold, and G. A. Johnson, "Development of Aircraft Lavatory Compartments with Improved Fire Resistance Characteristics — Phase II (Sandwich Panel Resin System Development)," NASA CR-152120, 1979.

6. ASTM G27-70, Standard Method for "Operating Xenon-Arc type Apparatus for Light Exposure of Nonmetallic Materials," American Society of Testing Materials, Washington, D.C.

7. R. A. Anderson, J. A. Carris, G. A. Johnson, and J. M. Peterson, "Development of Aircraft Lavatory Compartments with Improved Fire Resistance Characteristics — Phase III (Sandwich Panel Decorative Film Development)," NASA CR-166171, 1981.

Table 1. Test Procedure for Films: First, Second, and Third Screenings

First screening	Second screening	Third screening
Limiting oxygen index (LOI)[a]	Film screen-printed with white acrylic ink	Film bonded to three-ply phenolic/fiberglass composite and silicone adhesive
Smoke emission[a]		
Toxicity characteristics[a]	Ink compatibility Adhesion and flexibility Texture attainability	Flame spread[a] Smoke[a] Toxicity[a] Heat release[a]
Tensile strength		
Elongation	Un-screen-printed film	
	Ultraviolet stability Shrinkage	

[a] Tests considered essential screening criteria.

Table 2. Final Test Methods for Films.

Specimen type	Specimen configuration	Test method
Film laminate	Top film Substrate film	Thermal analysis Limiting oxygen index[a] Pyrolysis tube decomposition Peel strength Tensile properties Ultraviolet stability
Film laminate with phenolic/fiberglass composite plus adhesive	Top film Substrate film Densil 1078 (silicone pressure-sensitive adhesive) 3-Ply Ciba Geigy Fibredux 917G (phenolic/fiberglass impregnation)	Flame spread[a] 60-sec vertical flammability Smoke emission (NBS chamber)[a] Toxic gas emission (NBS chamber)[a] Heat release (OSU chamber)
Reinforced decorative laminate (incorporating canvas texture)	Top film Substrate film 1-Ply Ciba Geigy Fibredux 917G (phenolic/fiberglass impregnation)	Peel strength Taber abrasion

[a] Tests considered essential screening criteria.

Table 3. Description of candidate films.

Film number	Color	Chemical name	Trade name	Manufacturer
1	White[a]	Polyvinyl fluoride	Tedlar	Dupont
2	Opaque	Polyvinyl fluoride	FM Tedlar	Dupont
3	Clear yellow	Polyparabanic acid	Tradlon	Exxon
4	Amber	Polyimide	Kapton	Dupont
5	Clear	Polypropylene	Bicor 240B	Mobil
6	Clear	Polyester	ISO-BPE	Isovolta
7	Clear	Polycarbonate	Lexan	General Electric
8	White	Acrylic	Korad 6300	Korad
9	White	Polyamide	Nomex	Dupont
10	Clear	BPFC-DMS[b]	BPFC-DMS[b]	General Electric
11	Clear	Polyamide	Aramid Film A	Dupont
12	White	Polyester	Melinex 334	ICI
13	Clear	Polyethersulfone	PES 300P	ICI
14	Clear	Polymethylpentene	TPX	Mitsui
15	Clear yellow	Polyimide	DAPI-BTDA (B-100)	Ciba Geigy
16	Clear	Ionomer	Surlyn 1601	Dupont
17	Clear	Polyvinylidene fluoride	Fluorex HT-1	Rexham
18	Clear yellow	Polyphosphazene	1443-24-2	Horizons
19	Amber	Polybenzimidazole	PBI	Celanese
20	Clear	Polysulfone	Udel	Union Carbide
21	Cream	Polyphenylsulfone	Radel R5010	Union Carbide
22	White	Polyethylene	61079 Ascot	Appleton Papers
23	White	Polyester	Permacare IV 2693	Appleton Papers
24	Clear	Polyetheretherketone	PEEK	ICI

[a] baseline.

[b] Bisphenol fluorenone carbonate-dimethylsiloxane.

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Table 4. Film laminates considered in the final testing.

Film No.	Substrate film[a]
1	Baseline PVF
2	FM PVF
17	Polyvinylidene fluoride
11	Aramid polyamide
6	ISO-BPE polyester
24	PEEK polyethylethylketone

[a] All substrate films 0.051 mm with a top film of 0.028-mm baseline PVF.

Table 5. Relative ranking of films.[a]

Substrate film No.[b]	Substrate film, 0.051 mm[c]	Problems
24	Polyethylethylketone	Clarity, gel spots, width
11	Aramid polyamide	Low elongation, UV-unstable
6	ISO/BPE polyester	Brittle, low elongation
17	Polyvinylidene fluoride	HF evolution, does not bond to phenolic/fiberglass
2	FM PVF	HF evolution
1	Baseline PVF	HF evolution

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[a] Final relative ranking of film laminates was based on minimum physical properties and on LOI, flame spread, smoke emission, and toxicity.

[b] The most fire-resistant films are listed first.

[c] 0.025-mm baseline PVF was used as a top film.

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Figure 15. Test results of FAA flammability tests of films from the final testing. All film laminates were bonded to a single-ply phenolic/fiberglass composite.

Figure 16. Smoke-emission test results of films from the final testing. Films were tested in the NBS Chamber. All film laminates were bonded to a single-ply phenolic/fiberglass composite.

Figure 17. Results of CO emission tests of films from the final testing. Films were tested in the NBS Chamber. All film laminates were bonded to a single-ply phenolic/fiberglass composite.

Figure 18. Results of HF emission tests of films from the final testing. Films were tested in the NBS Chamber. All film laminates were bonded to a single-ply phenolic/fiberglass composite.

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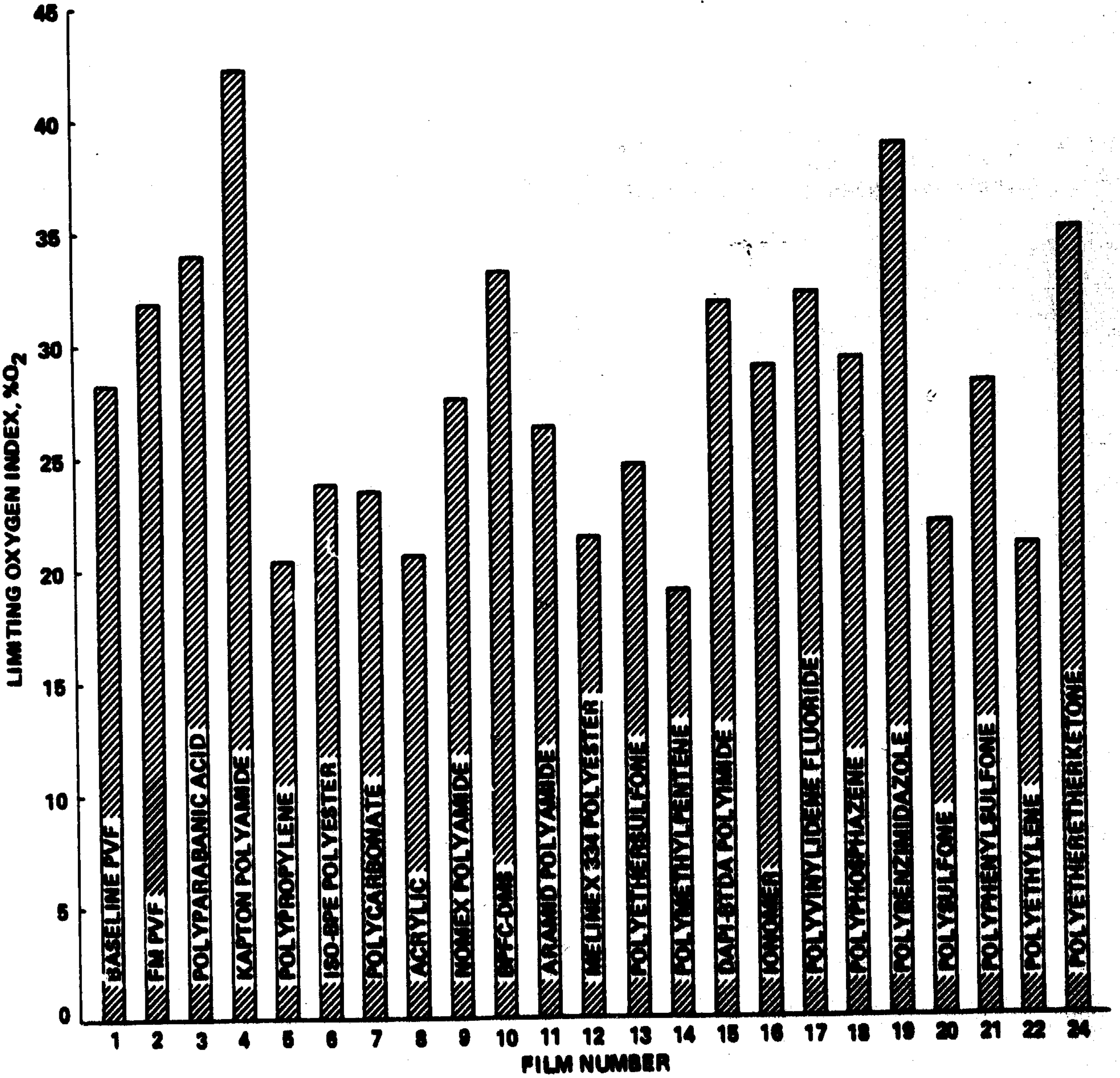


Fig. 1

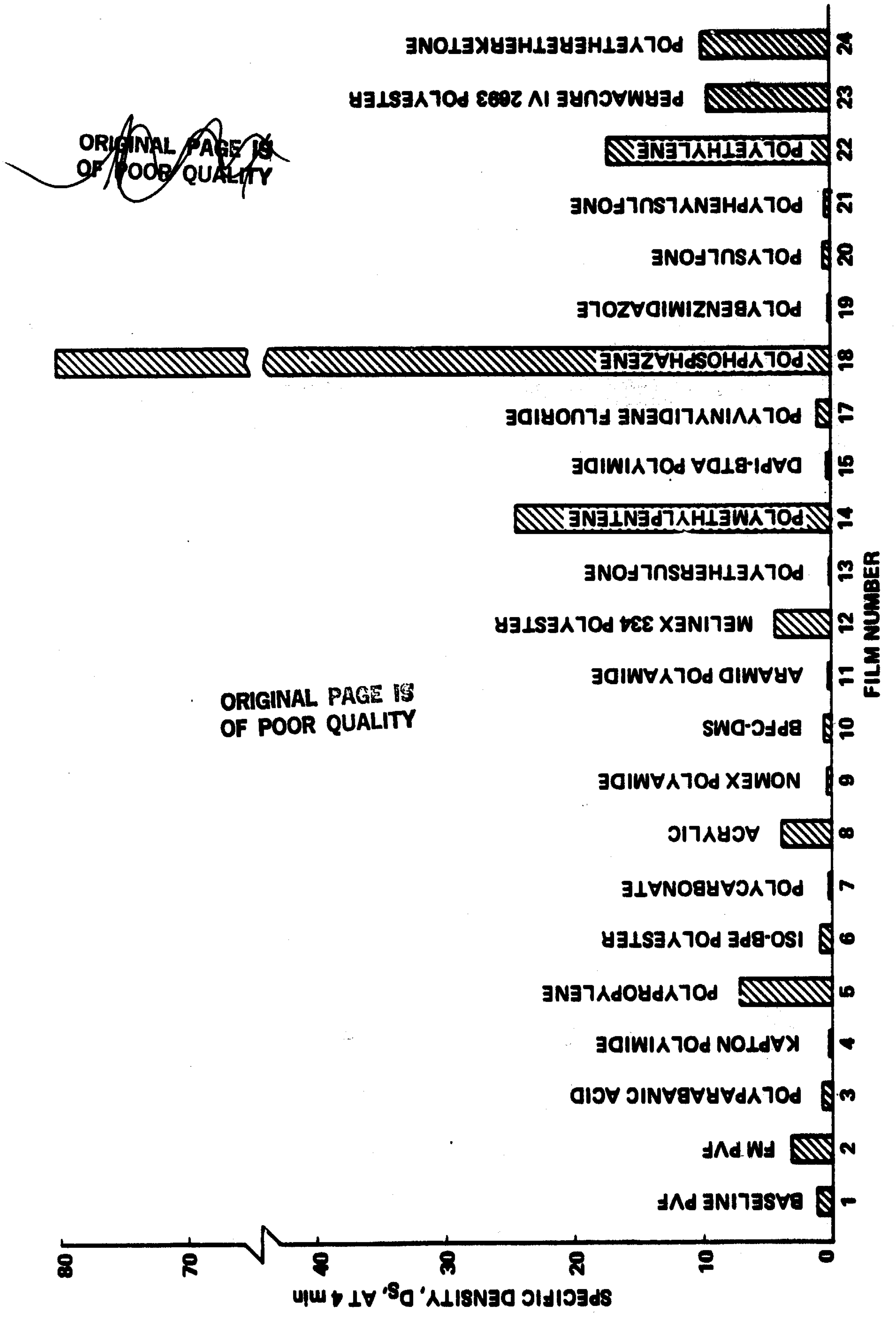
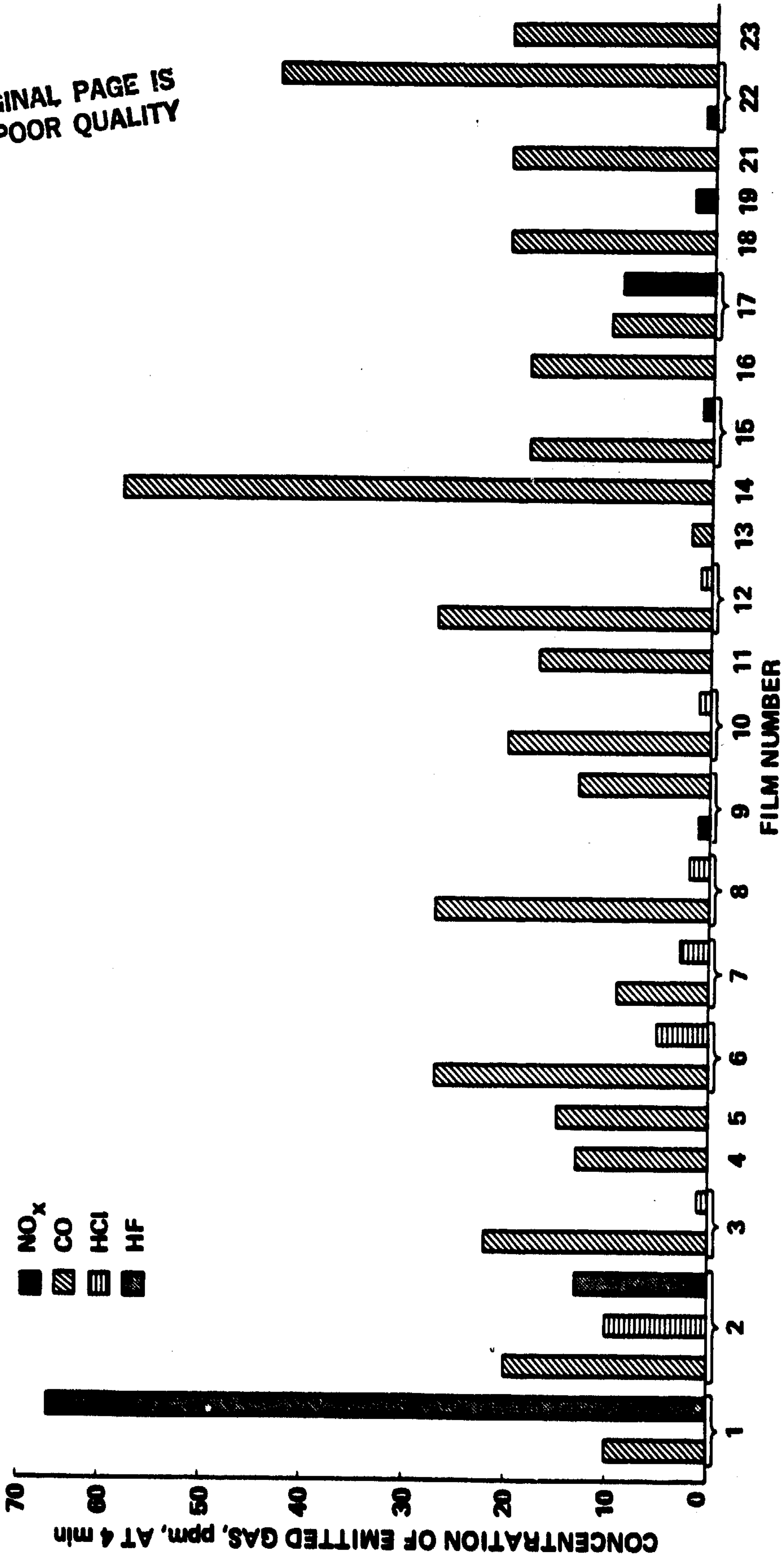

SPECIFIC DENSITY, D_s, AT 4 min
0
10
20
30
40
70
80
FILM NUMBER
1 BASELINE PVF
2 FM PVF
3 POLYPARABANIC ACID
4 KAPTON POLYIMIDE
5 POLYPROPYLENE
6 ISO-BPE POLYESTER
7 POLYCARBONATE
8 ACRYLIC
9 NOMEX POLYAMIDE
10 BPFC-DMS
11 ARAMID POLYAMIDE
12 MELINEX 334 POLYESTER
13 POLYETHERSULFONE
14 POLYMETHYLPENTENE
15 DAPI-BTDA POLYIMIDE
17 POLYVINYLIDENE FLUORIDE
18 POLYPHOSPHAZENE
19 POLYBENZIMIDAZOLE
20 POLYSULFONE
21 POLYPHENYLSULFONE
22 POLYETHYLENE
23 PERMACURE IV 2893 POLYESTER
24 POLYETHERETHERKETONE

Fig. 2


CONCENTRATION OF EMITTED GAS, ppm, AT 4 min
70
60
50
40
30
20
10
0
FILM NUMBER
1
2
3
4
5
6
7
8
9
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11
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Fig. 3

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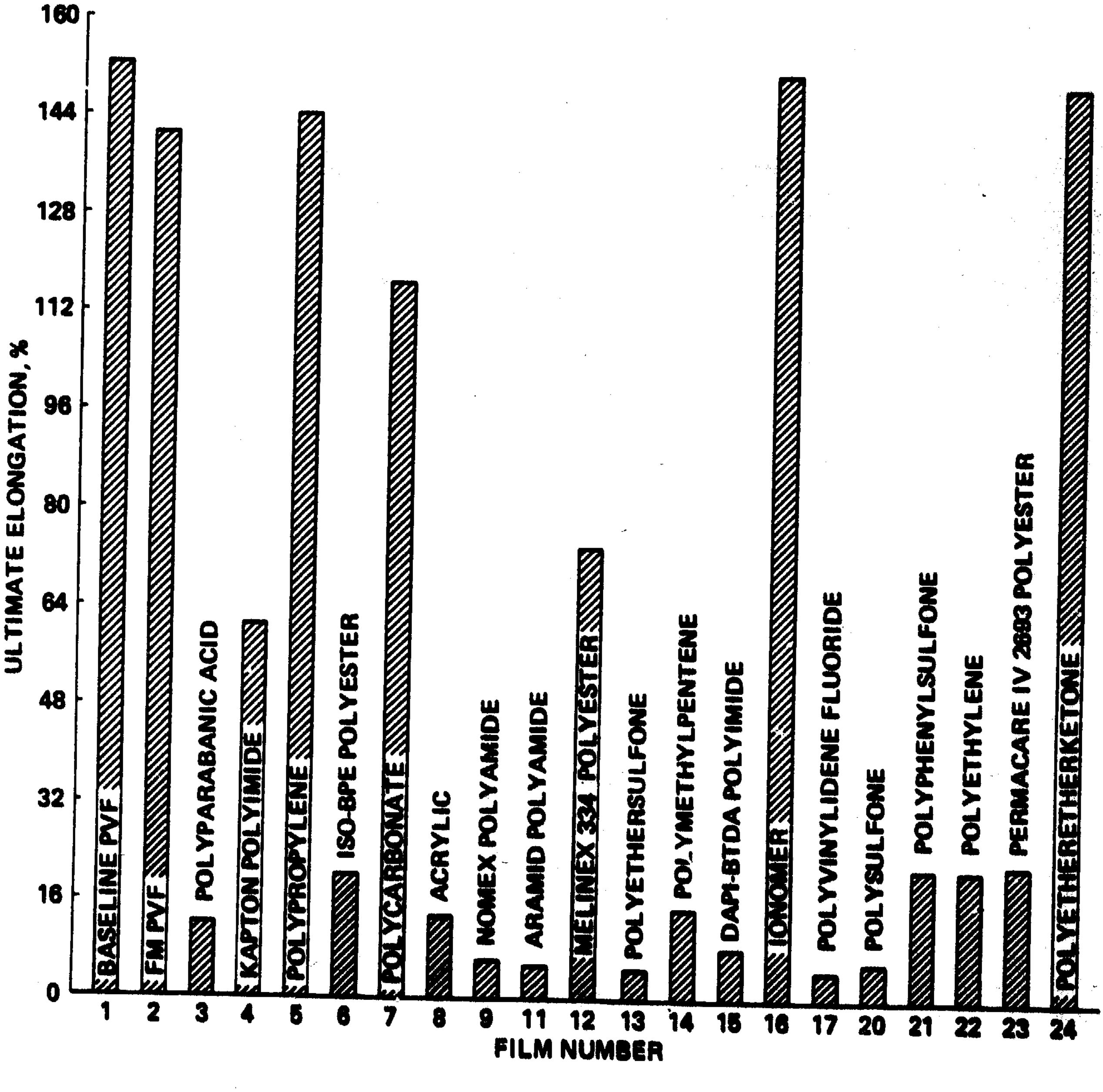

Fig. 4

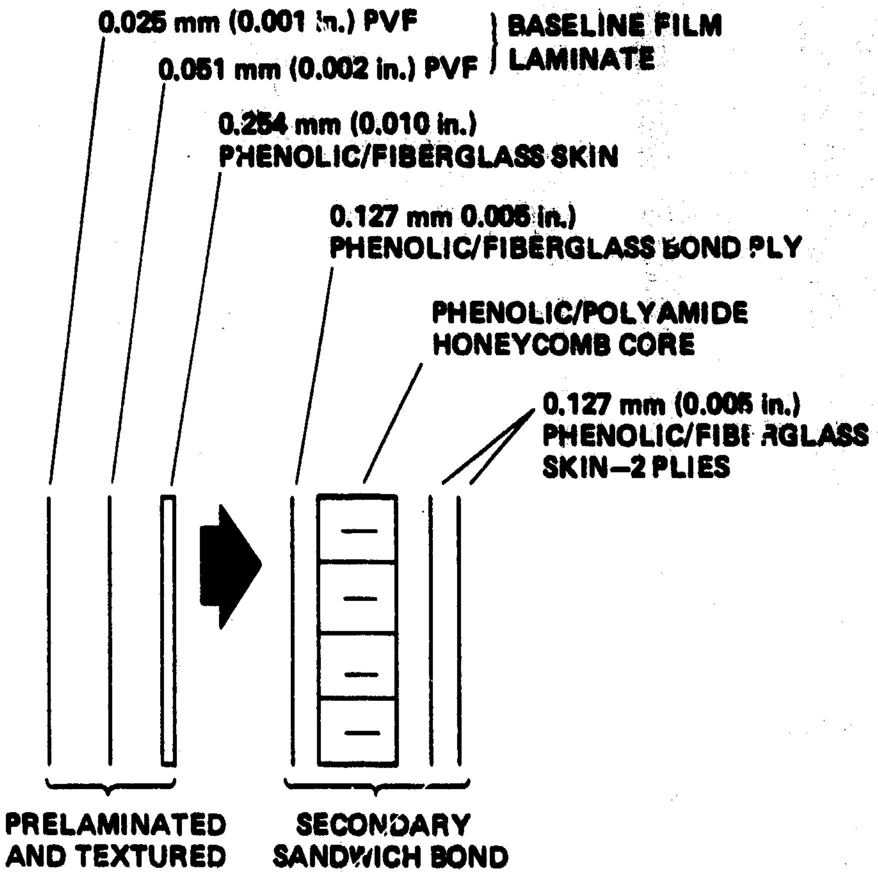
0.025 mm (0.001 in.) PVF
0.051 mm (0.002 in.) PVF
BASELINE FILM LAMINATE
0.254 mm (0.010 in.) PHENOLIC/FIBERGLASS SKIN
0.127 mm 0.005 in.) PHENOLIC/FIBERGLASS BOND PLY
PHENOLIC/POLYAMIDE HONEYCOMB CORE
0.127 mm (0.005 in.) PHENOLIC/FIBERGLASS SKIN—2 PLIES
PRELAMINATED AND TEXTURED
SECONDARY SANDWICH BOND

Fig. 5

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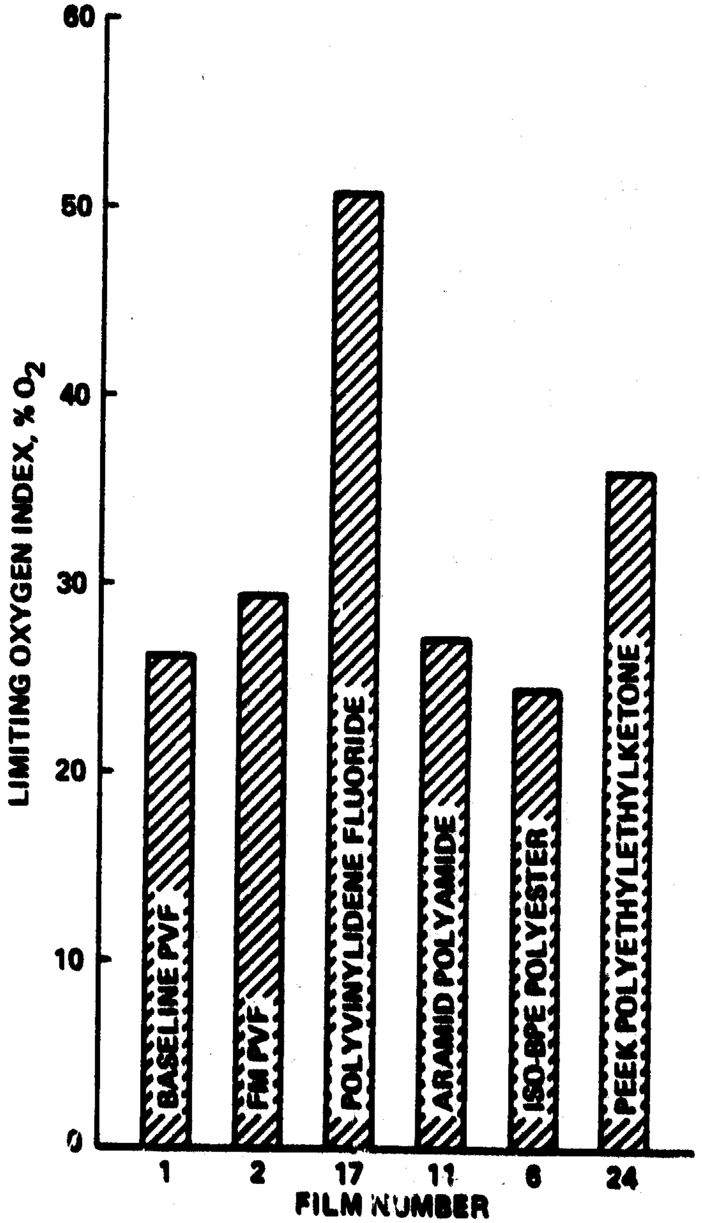

Fig. 6

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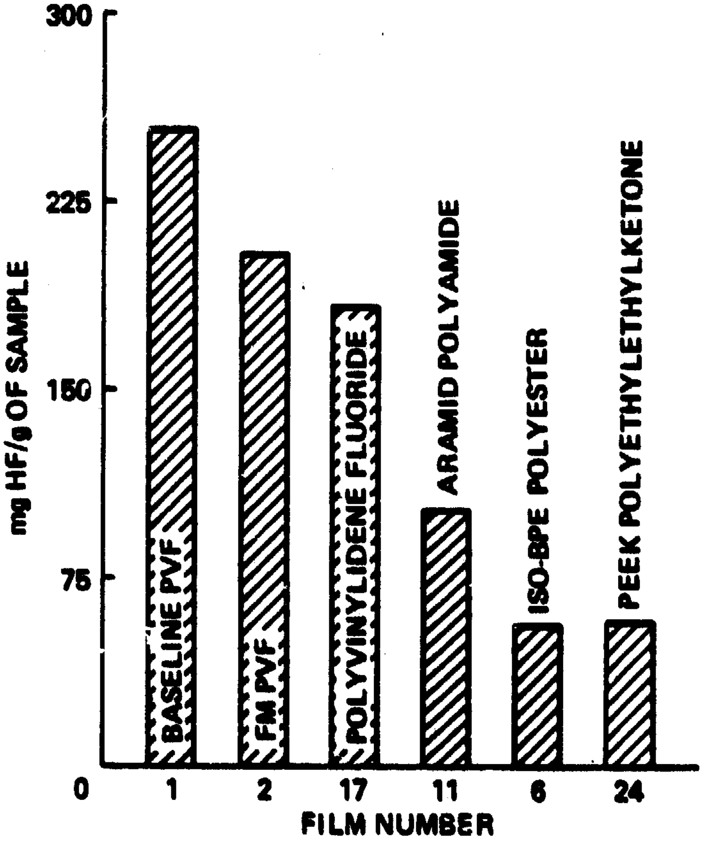

Fig. 7

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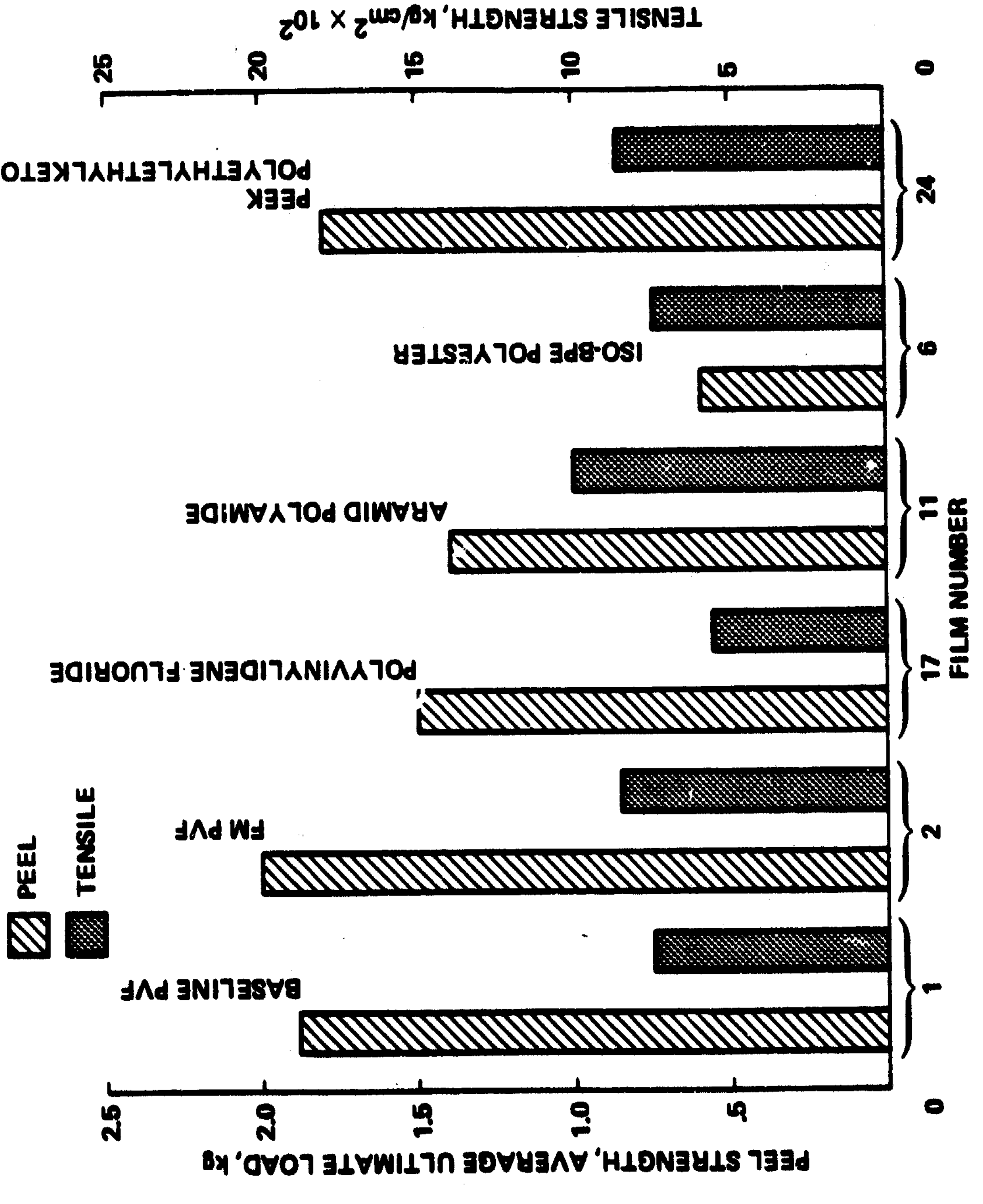

Fig. 8

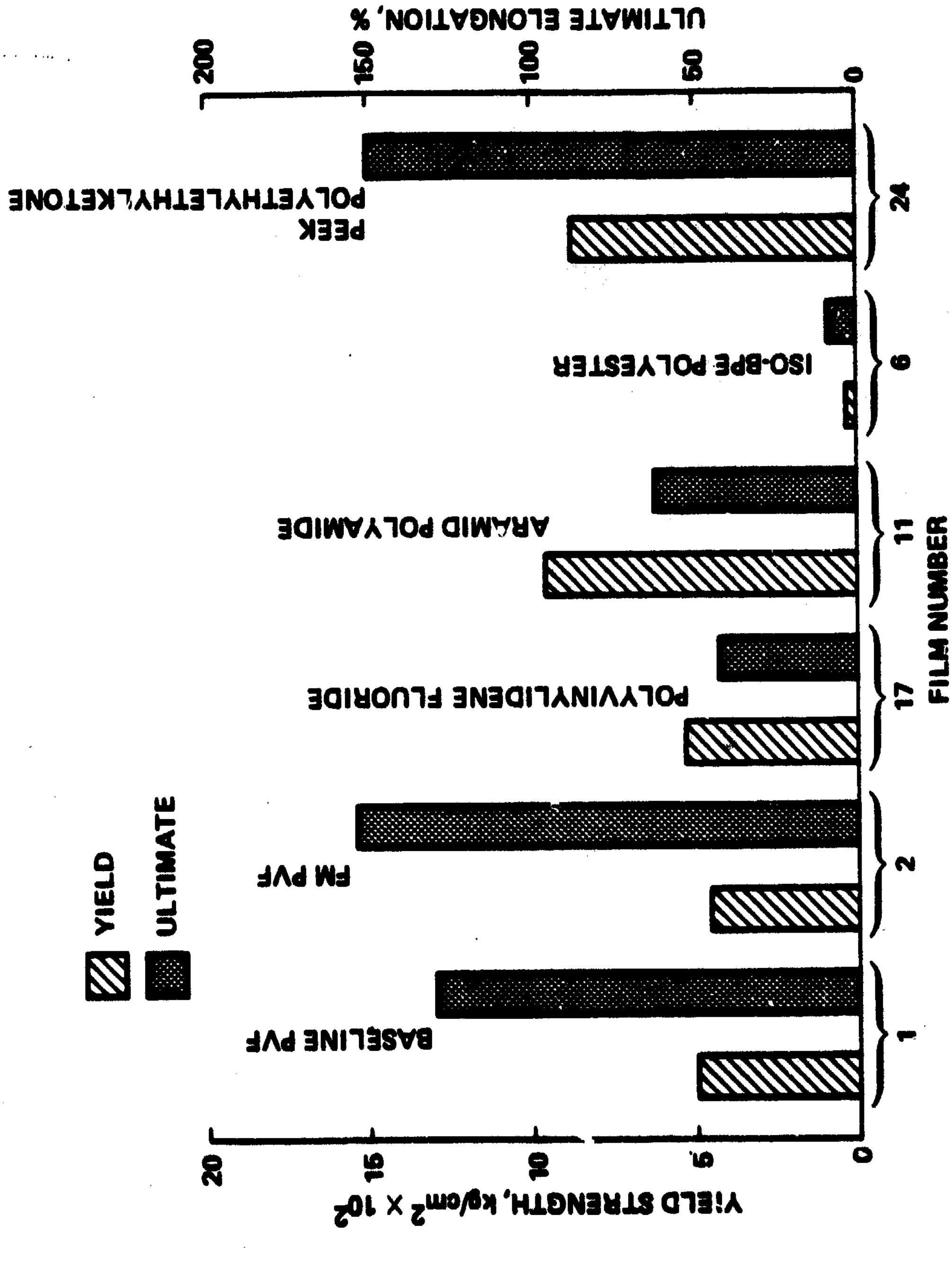
▨ YIELD
▩ ULTIMATE
YIELD STRENGTH, kg/cm^2 × 10^2
0
5
10
15
20
ULTIMATE ELONGATION, %
0
50
100
150
200
FILM NUMBER
1
BASELINE PVF
2
FM PVF
17
POLYVINYLIDENE FLUORIDE
11
ARAMID POLYAMIDE
6
ISO-BPE POLYESTER
24
PEEK
POLYETHYLETHYLKETONE

Fig. 9

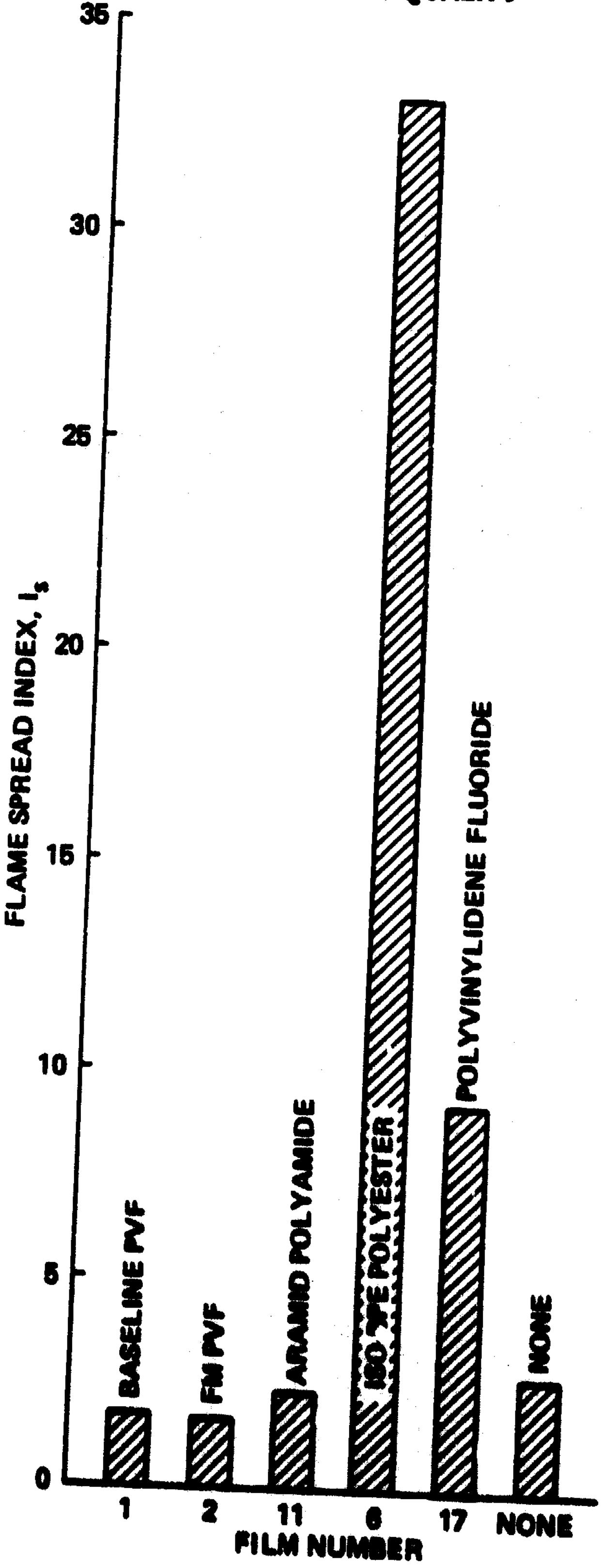
FLAME SPREAD INDEX, I_s
35
30
25
20
15
10
5
0
BASELINE PVF
FM PVF
ARAMID POLYAMIDE
ISO TYPE POLYESTER
POLYVINYLIDENE FLUORIDE
NONE
1
2
11
6
17
NONE
FILM NUMBER

Fig. 10

ORIGINAL PAGE IS
OF POOR QUALITY

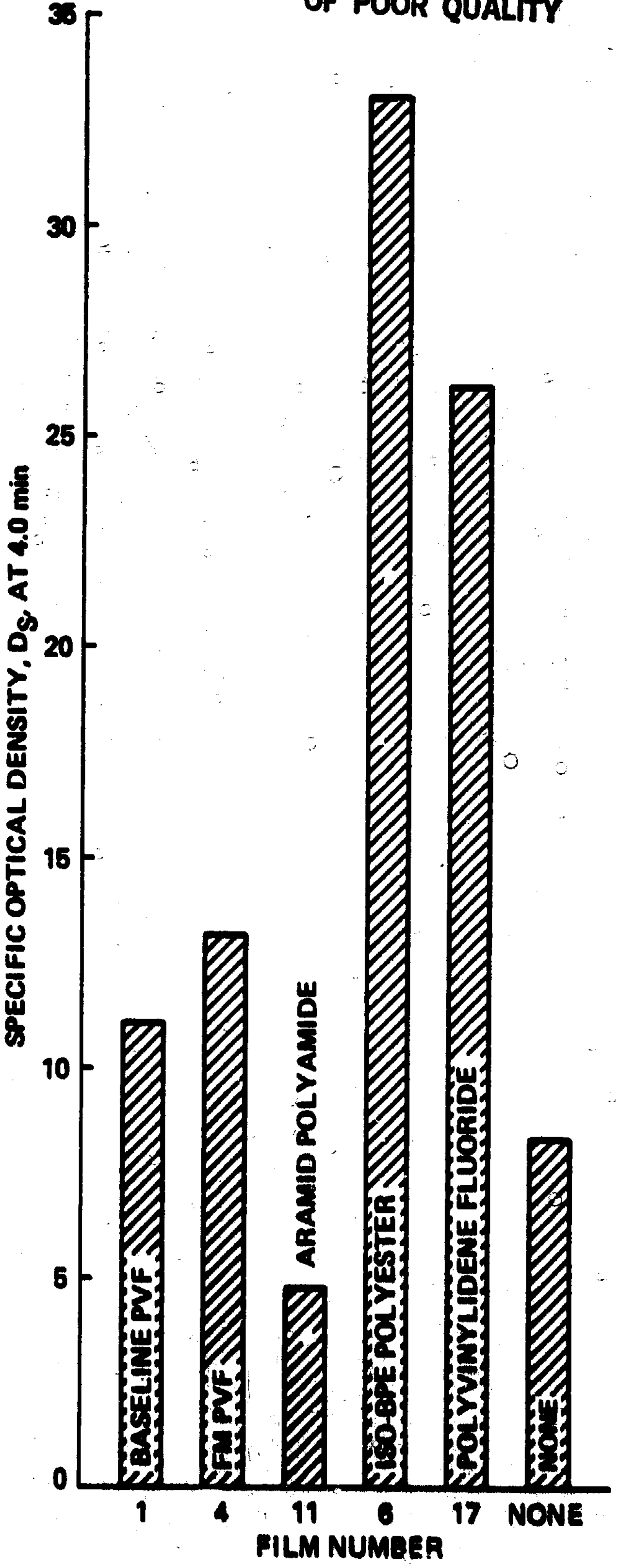

Fig. 11

ORIGINAL PAGE IS
OF POOR QUALITY

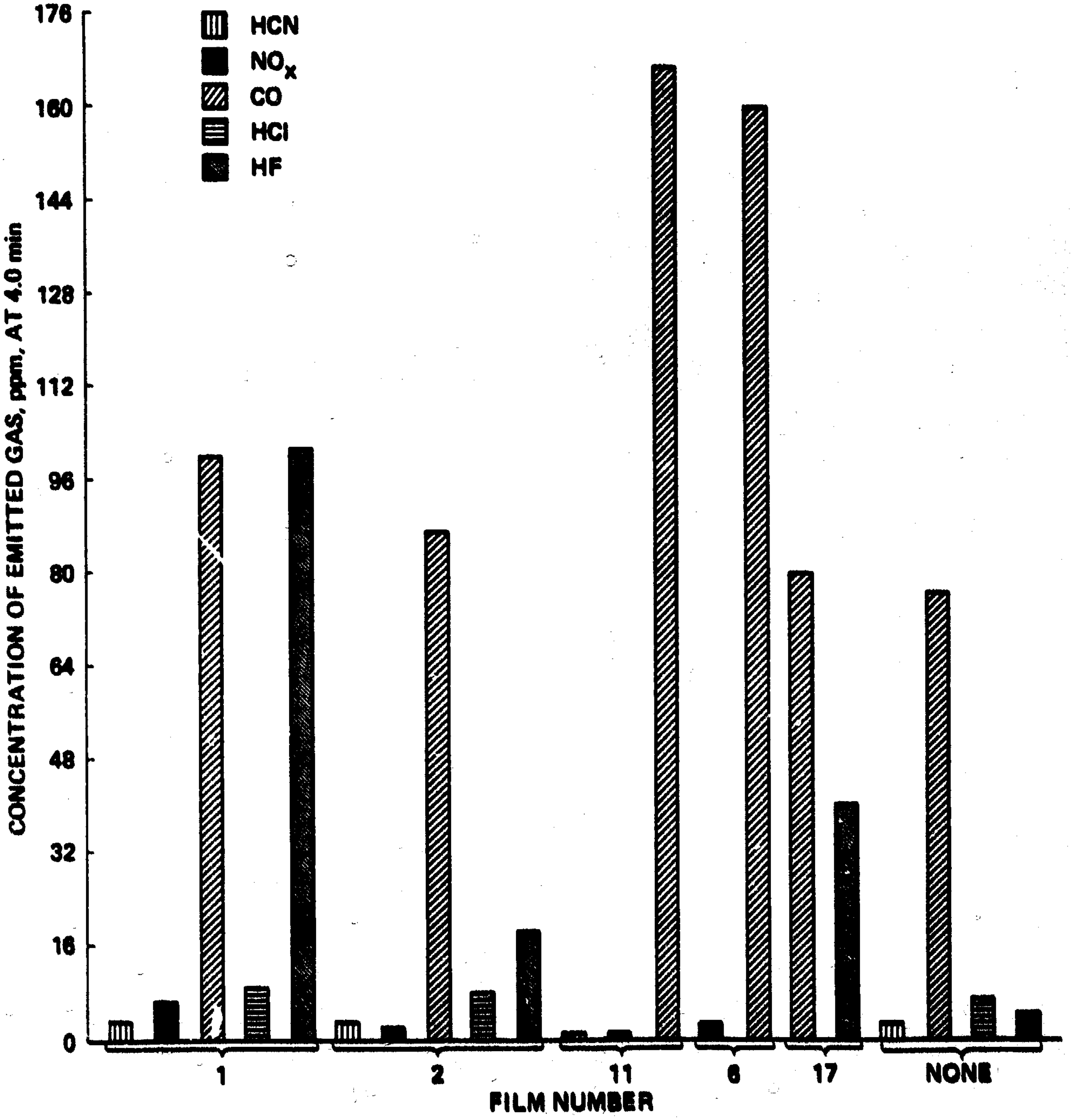

Fig. 12

ORIGINAL PAGE IS OF POOR QUALITY

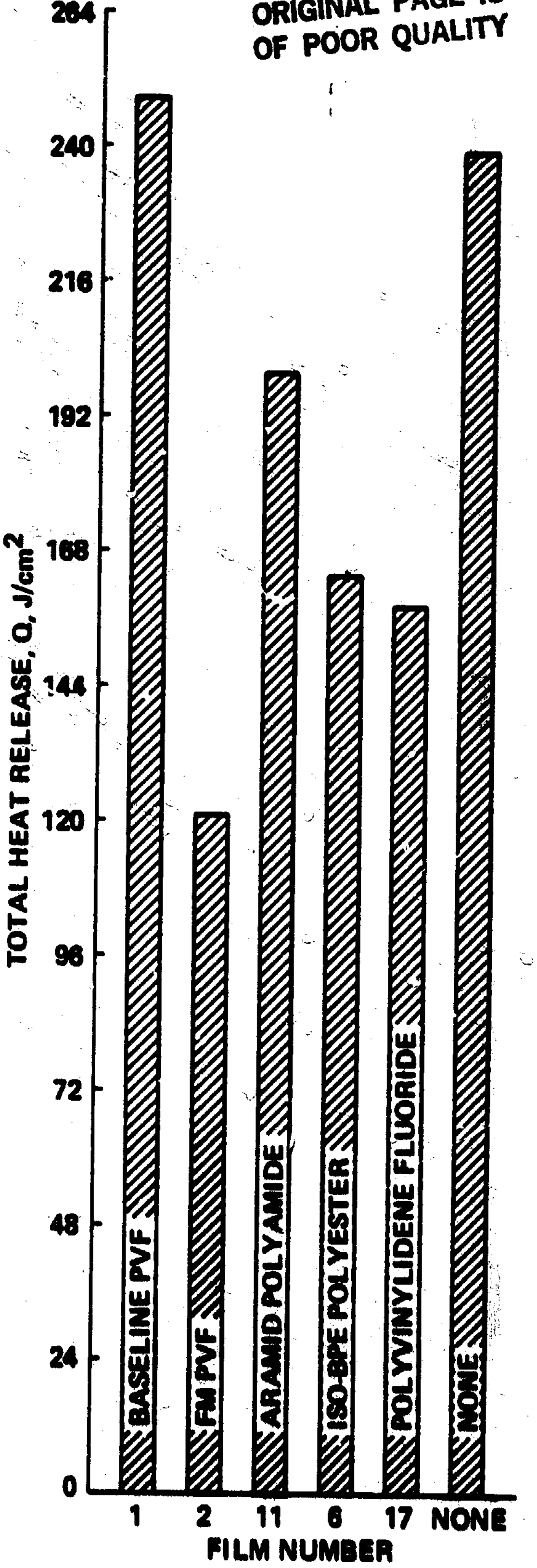

Fig. 13

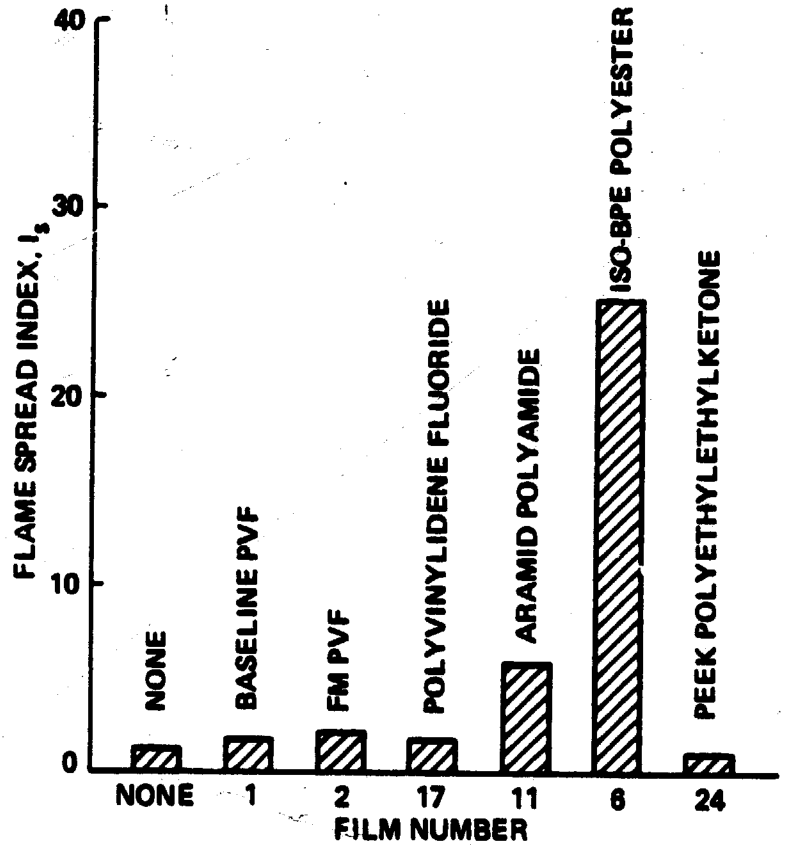
FLAME SPREAD INDEX, I_s
0
10
20
30
40
NONE
BASELINE PVF
FM PVF
POLYVINYLIDENE FLUORIDE
ARAMID POLYAMIDE
ISO-BPE POLYESTER
PEEK POLYETHYLETHYLKETONE
NONE
1
2
17
11
6
24
FILM NUMBER

Fig. 14

ORIGINAL PAGE IS
OF POOR QUALITY

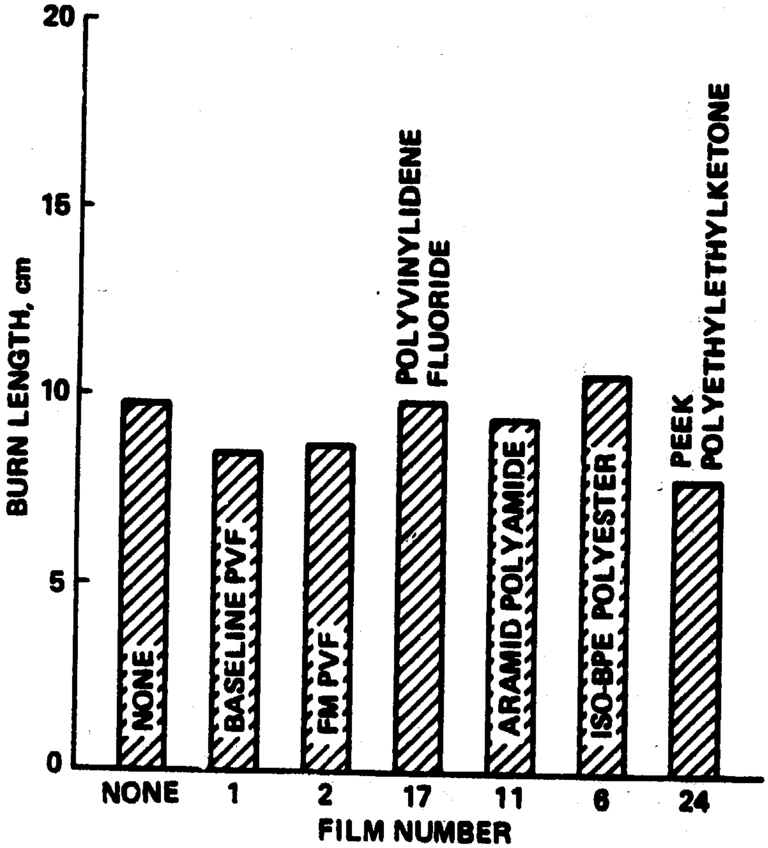

Fig. 15

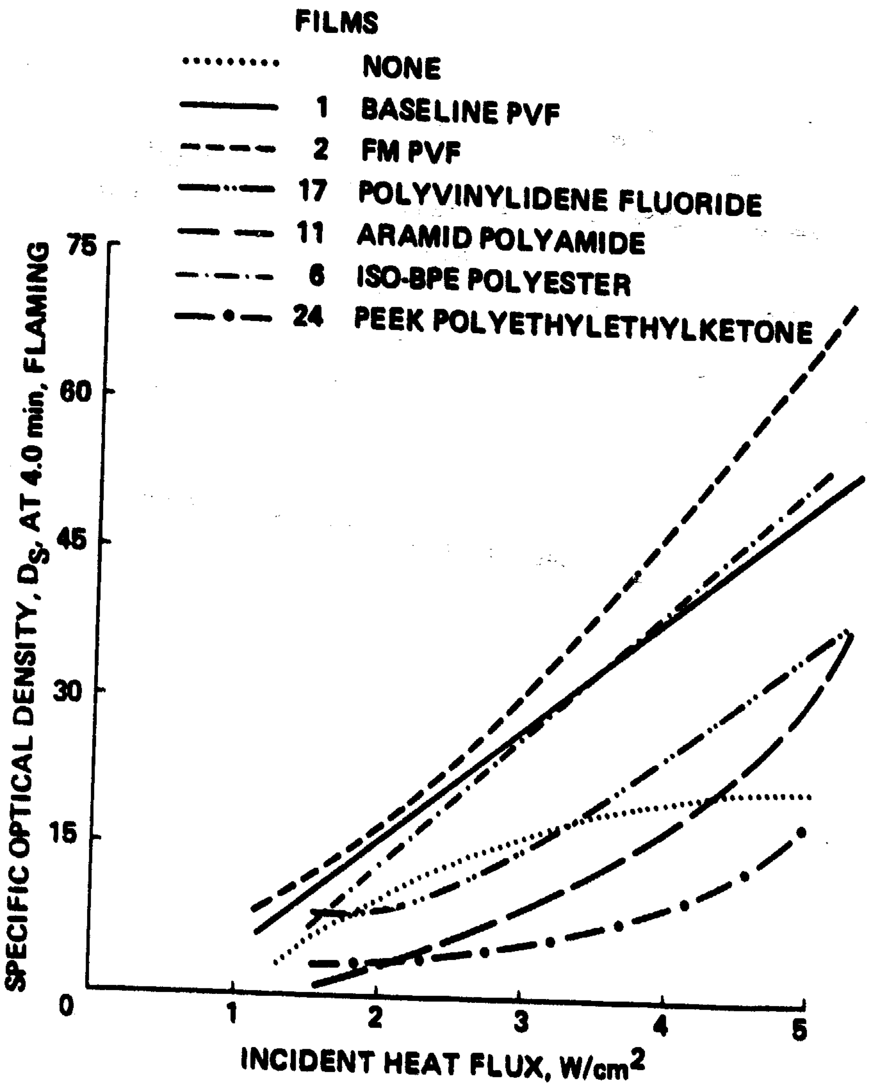
FILMS
NONE
1 BASELINE PVF
2 FM PVF
17 POLYVINYLIDENE FLUORIDE
11 ARAMID POLYAMIDE
6 ISO-BPE POLYESTER
24 PEEK POLYETHYLETHYLKETONE
SPECIFIC OPTICAL DENSITY, D_S, AT 4.0 min, FLAMING
75
60
45
30
15
0
1
2
3
4
5
INCIDENT HEAT FLUX, W/cm^2

Fig. 16

ORIGINAL PAGE IS
OF POOR QUALITY

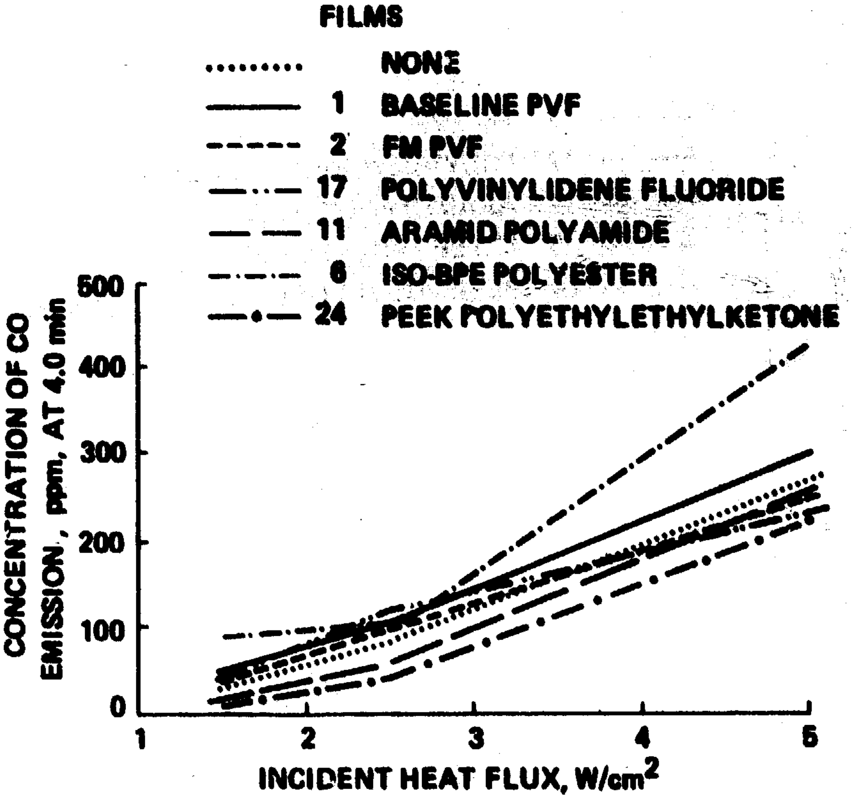

Fig. 17

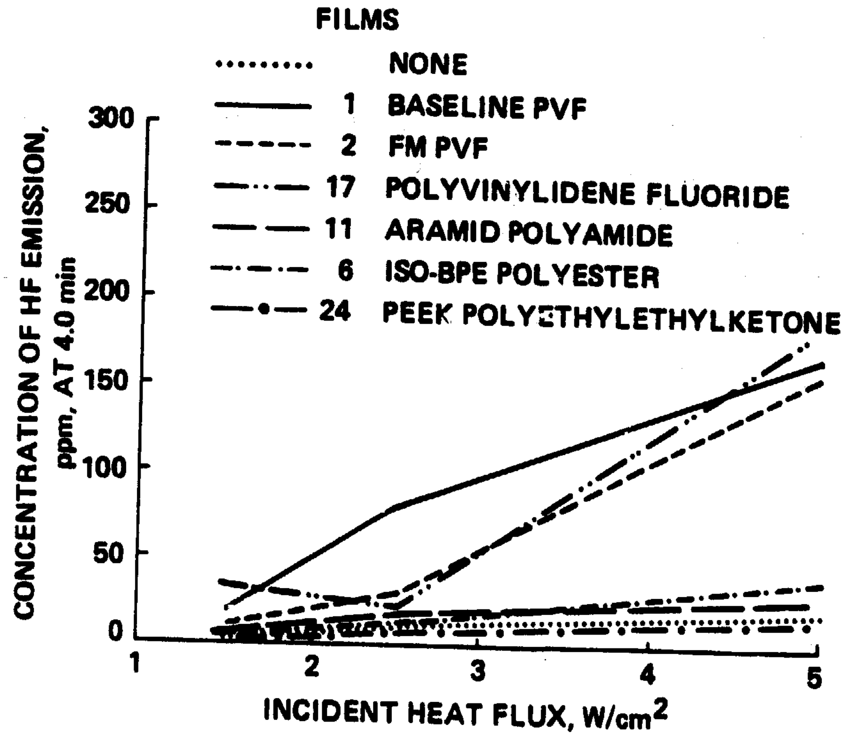
FILMS
NONE
1 BASELINE PVF
2 FM PVF
17 POLYVINYLIDENE FLUORIDE
11 ARAMID POLYAMIDE
6 ISO-BPE POLYESTER
24 PEEK POLYETHYLETHYLKETONE
CONCENTRATION OF HF EMISSION, ppm, AT 4.0 min
300
250
200
150
100
50
0
1
2
3
4
5
INCIDENT HEAT FLUX, W/cm²

Fig. 18