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Research paper

Fire resistance testing of aluminum-glass partitions

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Abstract: Glass-aluminum building facades, as well as glazed walls intended to construct internal partitions of various types with glass doors, the purpose of which is to create fire zones, must satisfy certain fire resistance requirements stated in the codes. The offer of domestic and foreign manufacturers consists of system fire resistant partitions manufactured in the EI 30 to EI 180 fire resistance classes. Fire retardant properties of such partitions are verified experimentally, and the technical approvals are issued based on the results of such tests. In this paper the results of fire tests performed on selected partitions made by the leading domestic maker of glass-aluminum systems and representative for the whole commercial offer of Aluprof S.A. are presented. Fire resistance of doors and partitions made of aluminum sections with fire protecting insulation in one or several chambers and Polflam glazing panes differing in thickness of swelling gel have been tested. In this paper a comparative analysis of the temperature increase curves obtained on the external surface of glass panes and aluminum sections forming the tested partitions has been performed. The relationships between the internal structure of aluminum sections and glazing panes and the shape of empirical curves have been indicated. A mixed tangent-secant linearization of these curves has been proposed as well as presentation of the experimental results in the non-dimensional coordinates. Such presentation form of final experimental results allows for a clear interpretation of laboratory tests with reliable documenting of nominal fire resistance requirements.

Keywords: aluminum, fire, fire resistance, glass, partitions, laboratory tests

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1. Introduction

Fire protecting properties of building elements, made of glass and aluminum sections, determine their ability to restrain fire propagation, by restricting the spread of fire to separated compartments [1, 2]. Fire resistance of glass building elements is measured according to various criteria [3–5], but in particular the requirements relate to: stability R (the glass does not break), tightness E, capability to restrict radiation W and insulation I. The tightness postulate E means, that the partition efficiently protects the fire compartment against flames, smoke and hot gases. The insulation postulate I means, that during the nominal fire duration period t_{nom} – the average glass pane temperature increase ΔT on the protected side of partition surface does not exceed the contractual value of 140°C, while the maximum temperature increases, of local character, do not exceed 180°C. Identical criterion of temperature increase $\Delta T \leq 180°\text{C}$ holds for the external surface of aluminum sections.

The tightness postulate E means that during the nominal time of fire test t_{nom}:

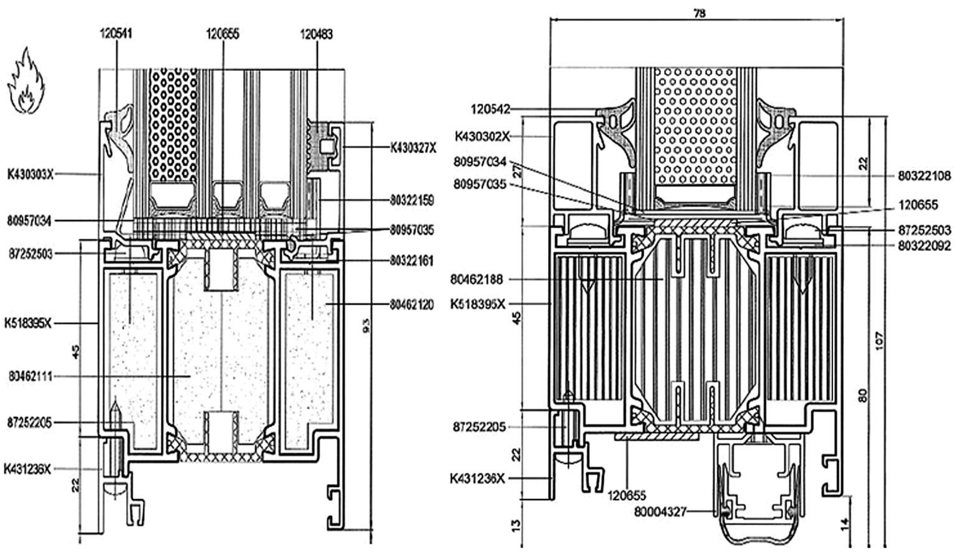
1) flame will not reach the outside for a time longer than 10 sec.,
2) the test cotton swab will not catch fire,
3) the cracks which may form will have an opening no larger than 6 mm or 25 mm.

Fire tests of glass-aluminum partitions allow for deformation measurements of whole partition. Those measurements complement the basic tests, i.e. tightness and insulation tests. The documented descriptions of partition behavior during fire test constitute an integral part of laboratory fire resistance tests. In the case of partitions glazed with fire resistant single chamber panes of the Polflam type the behavior of glass-aluminum structure in each of the cases analyzed here is the same. During the initial phase, corresponding to fire flashover, after 2.5–3 minutes of heating the test chamber the gel turns mat. This means that the gel had reached the temperature of approximately 120°C. In this temperature the gel expands, creating hard opaque surface constituting a temporary protection against high temperature. During the subsequent 3–5 minutes of heating the chamber, the glass panes on the heated side crack and fall into the furnace. The tested partition deforms towards the inside of the furnace, while the maximum displacements of columns and beams in the partition, of 80–120 mm in magnitude, are observed after about 20 minutes of heating. After that the displacements diminish to about 30–40 mm during the final stage of test. The local leaks in the partition, allowing for smoke coming out, may occur during the test, and in the final stage local sliding out of gaskets between the aluminum section and glass pane may also occur. In spite of permanent deformations the partitions do not lose the fire protecting properties until the end of the test. A similar course of the fire test is observed when the partitions glazed with multi-layered glazing panes of the Pyrobel or Pyrostop type are investigated. After 1.5–2 minutes of heating such panes whiten and crack on the heated side. During the following 2–5 minutes of heating the chamber, yellow spots appear on the panes and small leaks are observed in the corners, with egressing trickles of smoke. At the end of the test some gaskets fall out, the inside glass panes are cracked and the whole partition bulges towards the inside of the furnace.

2. Selected results of laboratory experiments

2.1. Fire resistance tests of Aluprof system doors

Laboratory fire resistance tests of Aluprof glass-aluminum systems are conducted separately for models of internal and external partitions and for doors installed in these partitions. When subjected to fire conditions, separation of those two glass-aluminum structures is justified by the extensive system of seals required to assure the tightness of various fire resistant door types [6, 7], cf. Fig. 1.



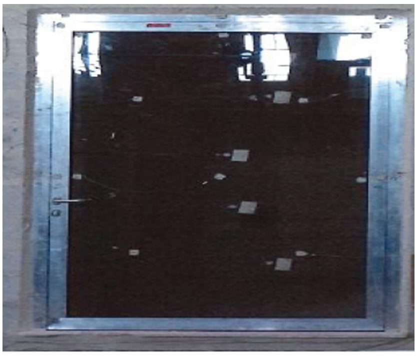
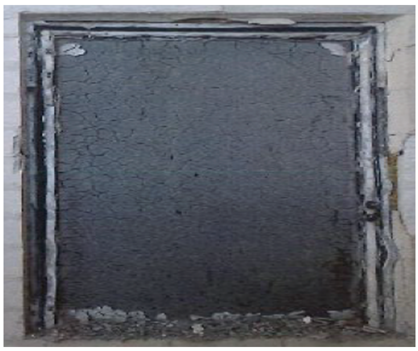
(a) (b)

Fig. 1. Structure of system doors: (a) with additional two chamber glazing, (b) without additional glazing

The external condition of tested door prior to and after fire test is depicted in the Table 1. The system doors of required nominal fire resistance $t_{\text{nom}} = 60$ min., model A and $t_{\text{nom}} = 90$ min., model B have been tested. Both tested components A and B have been constructed of aluminum sections made of EN AW 6060 alloy with thermal spacers made of polyamide reinforced with fiberglass. According to Fig. 1 the door sections of system doors are of three chamber structure filled with insulation inserts of varying in fire durability.

The thermal insulation of glazing in both cases has been made as a single chamber of the Polflam type, 25 mm thick (model (a)) and 32 mm (model (b)). In addition the test door of the type (a) had been glazed with two chamber glass pane, which is preferred in the outside walls, due to the climate insulation requirements. As indicated by the conducted fire test, this structural detail is important from the point of view of the fire resistance requirements related to glazing and the wall itself.

Table 1. Fire resistance tests of system doors with Polflam fire resistant glass panes and additional two chamber glazing (A) and without additional glazing (B)

	
A.1. Exteral view of MB-78 EI/60 door prior to the fire test LBO-1189/2018 [6]	A.2. Internal view of MB-78 EI/60 door after fire test (t = 63‘10“) [6]
	
B.1. Exteral view of MB-78 EI/90 door prior to the fire test LBO-1123/2018 [7]	B.2. Internal view of MB-78 EI/90 door after fire test (t = 92‘12“) [7]

The results of fire resistance tests conducted on the glazing of type A, in terms of the average temperature increase curves ΔT at testing stations, are depicted in Fig. 2, while the same curves pertaining to the model B are depicted in Fig. 3. In both test models these curves are of the rising type, but, as may be observed in Fig. 2 and Fig. 3, these curves are qualitatively different, in spite of the similar internal structure of the glazing (in the model A a single two chamber composite glass pane has been added, which changed the $\Delta T - t$ characteristics).

The manufacturers of glass-aluminum partitions offer commercially a variant of fire protecting doors fitted with opaque panels consisting of: outside steel panels 1 mm thick separated by a layer of mineral wool of 150 kg/m^3 density and thickness adjusted to conform to the required fire resistance t_{nom}. The results of tests of opaque doors with jamb made of MB-78/EI aluminum sections exhibiting nominal fire resistance EI 60 did not introduce any additional knowledge regarding the $\Delta T - t$ characteristics. Empirical curves for this

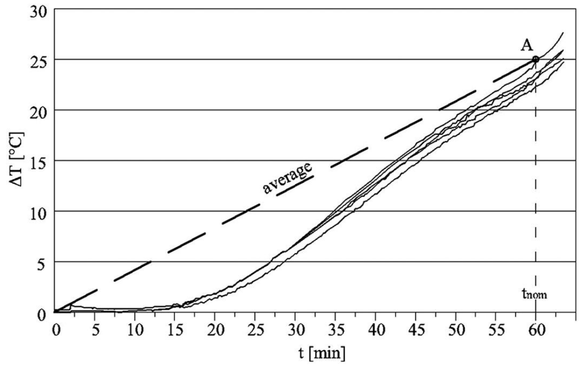


Fig. 2. Average temperature increase curves at points on the external surface of a composite two layer glass pane (glazed with fire resistant EI 60 Polflam glass) (A). Source [6]

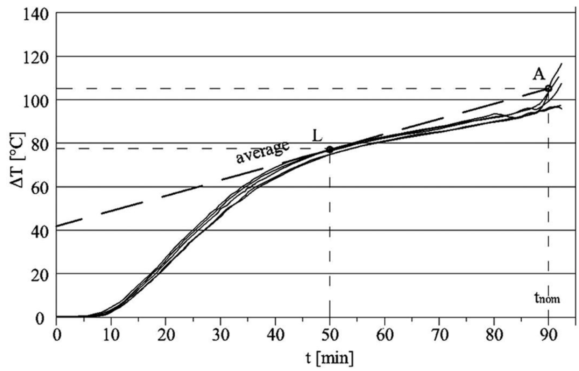


Fig. 3. Average temperature increase curves at points on the external surface of a fire resistant EI 90 Polflam glass (without additional composite glass pane) (B). Source [7]

model (denoted in this paper as model C) qualitatively conform to the curves depicted in Fig. 3, but with clear flattening observable along the LA section.

The results of ΔT temperature increase measurements on the external surface of aluminum jamb sections are typical for all three models A, B and C. The empirical curves of $\Delta T - t$ characteristics, representative for those structures are depicted at p. 2.2.

2.2. Fire resistance tests of the Aluprof system partitions

Of numerous experimental fire resistance tests conducted on Aluprof MB-78/EI and MB-118/EI system partitions, the following have been selected as representative for other similar structures:

a) fire resistance tests of an Aluprof MB-78/EI wall glazed with multi-layered panes of Pyrobel 16 type, exhibiting nominal fire resistance EI 30, denoted as test model D [8],

b) fire resistance tests of an Aluprof MB-78/EI wall glazed with single chamber panes of Polflam type, exhibiting nominal fire resistance EI 90, denoted as test model E [9],
c) fire resistance tests of an Aluprof MB-118/EI wall glazed with single chamber panes of Polflam type, exhibiting nominal fire resistance EI 120, denoted as test model F [10],
d) fire resistance tests of an Aluprof MB-118/EI wall glazed with multi-layered panes of type Pyrostop 120-10, exhibiting nominal fire resistance EI 120, denoted as test model G [11],

Of the test models listed above, the models F, and G depicted on Fig. 4 and Fig. 5 represent the most developed structural system. Aluminum sections in both versions are of the five chamber type filled with insulation inserts made of plasterboard (external chambers) and CI insulating inserts (central chamber).

Fig. 4. View of the MB-118/EI system partition test element (partition G). Source [11]

Glass panes of the partition G are made of multi-layered 120-10 Pyrostop type glass, having a total thickness of 58 mm, while in the partition G single chamber 35 mm thick glazing of the Polflam type is used.

The results of fire resistance tests expressed as functions of temperature increase ΔT versus heating time t (cf. for example. Fig. 6), at measurement stations located on the external surface of aluminum sections and glazing panes are similar for the considered test models, thus only selected results, representative for the remaining cases are depicted below.

In particular, the $\Delta T - t$ characteristics typical for aluminum sections of the type G, with five chamber insulation according to Fig. 5, are depicted in Fig. 6. The analyzed curves are characterized by the inflection point at the initial phase of section heating and quasi-linear

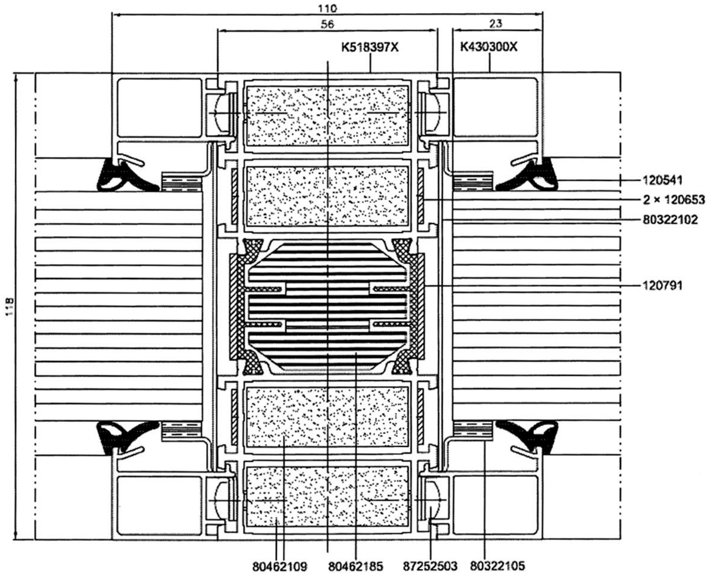


Fig. 5. Structure of the columns and beams and multi-layered glass panes (partition G)

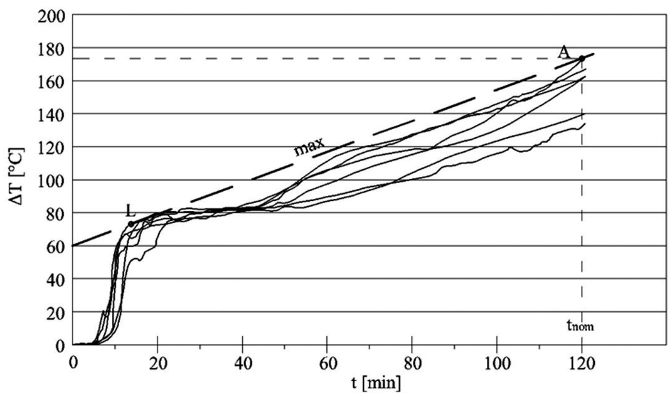
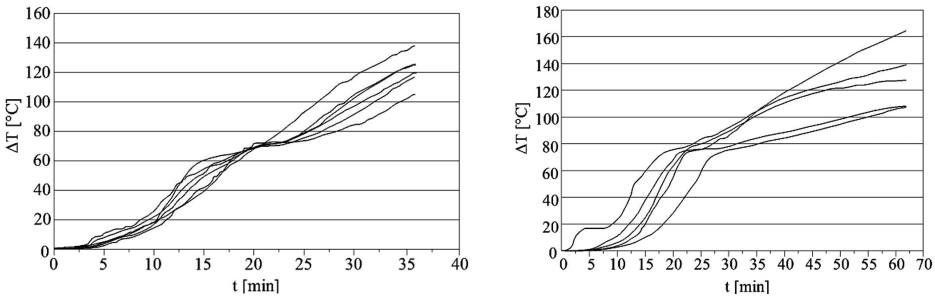


Fig. 6. Typical temperature increase curves at measurement stations located on the external surface of aluminum sections – insulation in five chambers, EI 120 according to the report LPP02/2020. Source [11]

behavior of the temperature increase beyond that point. Qualitatively and quantitatively convergent results have been obtained during a fire resistance test conducted on partition F made of aluminum sections exhibiting identical internal structure and nominal partition heating time $t_{\text{nom}} = 120$ min.

The sample $\Delta T - t$ temperature increase characteristics for aluminum sections, obtained during fire tests of shorter heating time duration and single and three chamber insulation are depicted in Fig. 7. In particular, the curves on Fig. 7a have been obtained during tests conducted on model D with insulation in single chamber, while the curves on Fig. 7b have been obtained during tests conducted on model A with fireproofing insulation in three chambers.



(a) (b)

Fig. 7. Temperature increase curves at measurement stations located on the external surface of sections MB-78/EI: (a) EI 30 – insulation in single chamber [8]; (b) EI 90 insulation in three chambers [9]

The (maximum and minimum) temperature increase curves on the external glazing surface of test models F and G are in both cases qualitatively different: for multi-layered glass panes according to Fig. 8 the curves are of rising character, while for single chamber panes according to Fig. 9 – curves exhibit inflection point.

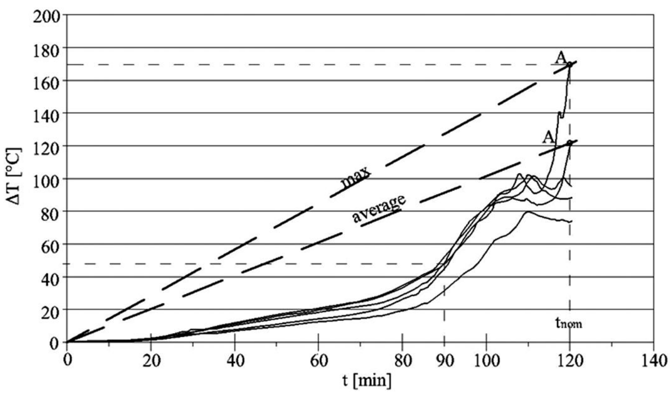


Fig. 8. Typical temperature increase times at test stations located on the external surface of the multi-layered glazing panes (120-10 Pyrostop glass, EI 120), according to the report LPP02/2020 [11]

Thus the character of $\Delta T(t)$ depends on the structure of glazing panes. Multilayered glazing panes applied in the model G are characterized by increasing $\Delta T(t)$ functions with inflection point located near the nominal temperature $t_{\text{nom}} = 120°\text{C}$ (cf. Fig. 8). In the single chamber glazing panes the inflection point is located at the initial phase of heating near the temperature of $0.3\ t_{\text{nom}} = 40°\text{C}$ (cf. Fig. 9). The indicated rule has been confirmed during fire tests performed on the other test models, during shorter partition heating time.

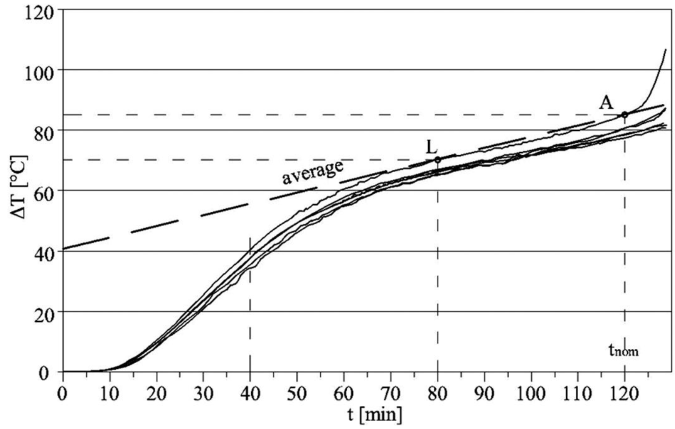


Fig. 9. Typical average temperature increase times at test stations located on the external surface of the single chamber glazing panes (Polflam glass, EI 120), according to the report LBO-1335/2019 [10]

3. Linearization of the temperature increase curves

Numerous empirical graphs of $\Delta T(t)$ characteristics may not be directly compared, due to the different requirements pertaining to the fire resistance of partition components – t_{nom}. In order to allow for a comparative analysis, linearization of temperature increase curves is suggested, and expression of these curves in non dimensional coordinates.

The assumed linearization of empirical temperature increase curves on the external surface of tested glazing panes and aluminum sections is depicted in Fig. 2, Fig. 3, Fig. 6, Fig. 8 and Fig. 9. In each case the cluster of empirical curves is bounded at the top by two linearization nodes denoted on the graphs as nodes A and L.

Point A is determined as an intersection of a vertical t_{nom} line with the top (extreme) empirical $\Delta T(t)$ temperature increase curve. Point L is defined as a tangent point of the LA line with extreme empirical curve, and for empirical curves devoid of a clear inflection point, the origin of the coordinate system. Such case occurs for instance in Fig. 2, where point A is determined as an intersection point of the $t_{\text{nom}} = 60°\text{C}$ line and the extreme empirical curve, while point L coincides with the origin of the coordinate system. This regularization rule has been applied as well in Fig. 3, where point A is determined as the intersection point of the $t_{\text{nom}} = 90°\text{C}$ line and the extreme empirical curve, while point L is defined as the tangent point of the LA line and the same curve at the abscissa $t = 50°\text{C}$. The linearization results of all considered cases are juxtaposed in the Table 2, where the coordinates of the linearization node A and the coordinate of the line intersection point with ordinate axis are given. The results listed in Table 2, but expressed in non dimensional coordinates are presented in Table 3. For that purpose the results contained in the Table 2 have been divided by appropriate limit values ($\Delta T/140°\text{C}$ or $\Delta T/180°\text{C}$) and the partition heating time t has been divided by the nominal fire resistance t_{nom}. Linearized "envelopes" of the of temperature increase curves on the external surface of aluminum sections measured during fire resistance tests of Aluprof system doors and partitions are depicted in Fig. 10, while the temperature increase lines measured on the external surface of glass panes in analyzed partition fire resistance test cases are depicted in Fig. 11.

Table 2. Coordinates of the average and maximum temperature increase linearization nodes on the external (unheated) surface of glass panes and aluminum sections

No	Glass/pane				No	Jamb/wall sections	
	Average temperature increase in time t_{nom}		Maximum temperature increase in time t_{nom}			Temperature increases in time t_{nom}	
	ΔT_0 [°C]	ΔT_A [°C]	ΔT_0 [°C]	ΔT_A [°C]		ΔT_0 [°C]	ΔT_A [°C]
A. Fire tests of Aluprof MB-78/EI system door, Polflam glass EI 60 acc. to LBO-1189/18							
1	0	25	0	95	1	35	160
					2	30	178
B. Fire tests of Aluprof MB-78/EI system door, Polflam glass EI 90 acc. to LBO-1123/18							
2	50	100	30	155	3	60	146
					4	52	187
C. Fire tests of Aluprof MB-78/EI system door EI 60 type, opaque panels acc. to the report LZP01-01036/19/R426NZP							
3	55	105	70	90	5	80	175
					6	50	165
D. Fire tests of the Aluprof MB-78/EI system wall, Pyrobel 16 glass, EI 30 acc. to LBO-1339/19							
4	80	120	72	112	7	12	112
5	72	86	62	109	8	5	114
6	70	105	80	110			
E. Fire tests of the Aluprof MB-78/EI system wall, Polflam glass, EI 90 acc. to LBO-446/13							
7	48	81	–	–	9	60	120
8	43	81	–	–	10	66	120
F. Fire tests of the Aluprof MB118/EI system wall, Polflam glass, EI 120 acc. to LBO-1335/19							
9	40	85	52	85	11	70	114
10	40	85	60	85	12	65	95
11	42	84	58	85			
G. Fire tests of the Aluprof MB-1188/EI system wall, Pyrostop 120-10 glass, acc. to LPP02/20							
12	0	120	0	168	13	60	176
13	0	86	0	86	14	60	206
14	0	104	0	104			

Table 3. Non dimensional coordinates of linearization nodes for glass and section

Line designation	Increase of average temperature		Line designation	Increase of maximum temperature	
	$\frac{\Delta T_0}{140°C}$	$\frac{\Delta T_A}{140°C}$		$\frac{\Delta T_0}{180°C}$	$\frac{\Delta T_A}{180°C}$
Fire tests of Aluprof MB-78/EI system door glass panes					
$\overline{A}$	0	0.179	A	0	0.528
$\overline{B}$	0.357	0.714	B	0.167	0.861
$\overline{C}$	0.393	0.750	C	0.389	0.500
Fire tests of Aluprof MB-78/EI and MB-118EI partition glass panes					
$\overline{D}_4$	0.571	0.857	D_4	0.400	0.622
$\overline{D}_5$	0.514	0.614	D_5	0.344	0.606
$\overline{D}_6$	0.500	0.750	D_6	0.444	0.611
$\overline{E}_7$	0,343	0,579	E_7	–	–
$\overline{E}_8$	0.307	0.579	E_8	–	–
$\overline{F}_9$	0.286	0.607	F_9	0.289	0.472
$\overline{F}_{10}$	0.286	0.607	F_{10}	0.333	0.472
$\overline{F}_{11}$	0.300	0.600	F_{11}	0.322	0.472
$\overline{G}_{12}$	0	0.857	G_{12}	0	0.933
$\overline{G}_{13}$	0	0.614	G_{13}	0	0.478
$\overline{G}_{14}$	0	0.743	G_{14}	0	0.578
Fire tests of Aluprof system aluminum sections used to make door and partitions					
Line designation	Temperature increase		Line designation	Temperature increase	
	$\frac{\Delta T_0}{180°C}$	$\frac{\Delta T_A}{180°C}$		$\frac{\Delta T_0}{180°C}$	$\frac{\Delta T_A}{180°C}$
Fire tests of Aluprof MB-78/EI system door jamb and leaf					
A_1	0.194	0.889	A_2	0.167	0.989
B_3	0.333	0.811	B_4	0.289	**1.039**
C_5	0.444	0.972	C_6	0.278	0.917
Fire tests of Aluprof MB-78/EI and MB-118/EI system aluminum partition sections					
D_7	0.067	0.622	D_8	0.028	0.633
E_9	0.333	0.667	E_{10}	0.367	0.667
F_{11}	0.389	0.633	F_{12}	0.361	0.528
G_{13}	0.333	0.978	G_{14}	0.333	**1.144**

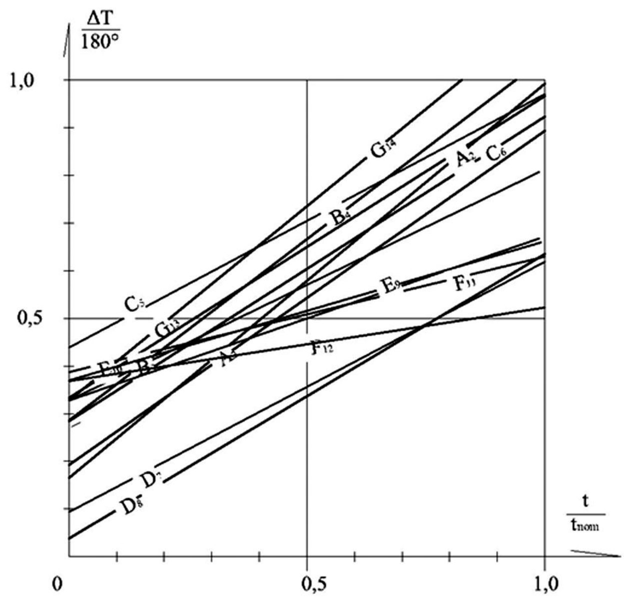


Fig. 10. Linearized envelopes of the temperature increase curves determined on the external surface of aluminum sections during fire tests of Aluprof system doors and partitions

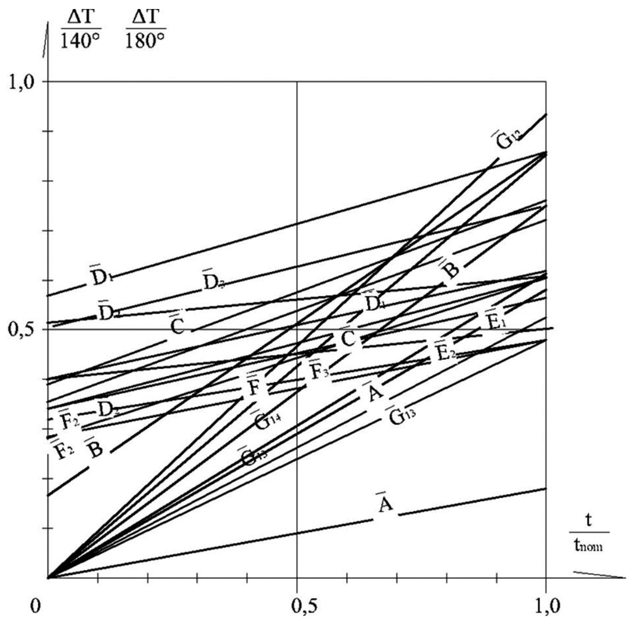


Fig. 11. Linearized envelopes of the temperature increase curves on the external surface of glazing panes during fire tests of doors and partitions: A and G – layered or two chamber glazing, C, D, E, F – one chamber glazing

4. Summary

The laboratory fire resistance tests conducted in the course of attestation process have been performed by accredited test labs, which are independent of the manufacturer. Fire resistance of doors and partitions made of aluminum sections with fireproofing insulation in one or several chambers and multi-layered or single chamber glass panes differing in swelling gel layer thickness has been determined experimentally. The results of tests fully confirmed the fire resistance of MB-78EI and MB-118EI system doors and partitions declared in the manufacturer specifications. The temperature increase ΔT on the external surface of aluminum sections and glass panes during the heating time t is the basic feature controlled during fire resistance tests. Comparative analysis of the experimental results taken into account in this paper has shown, that the structure of glass panes substantially affects the shape of the $\Delta T(t)$ function. In particular, the multi-layered glass panes are characterized by an increasing $\Delta T(t)$ function devoid of clear inflexion point. Single chamber glass panes, filled with swelling gel, in each analyzed case are characterized by a clear inflexion point of the $\Delta T(t)$ curves, located in the developed phase of partition heating at about $0.3t_{\text{nom}}$ (cf. Fig. 3 and Fig. 9). Qualitatively different shape of the $\Delta T(t)$ curve is observed for multi-layered glass panes, as the temperature increase curves in such case do not exhibit a clear inflexion point (cf. Fig. 8). For such structure of glass panes a safe secant linearization with linearization point coinciding with the origin of the coordinate system is possible (cf. Fig. 8).

A quite surprising result has been documented during fire test of single chamber Polflam panes with additional two chamber glazing using ordinary glass, cf. Fig. 2. The glazing obviously changed the $\Delta T(t)$ characteristic, to a quasi multi-layered type, devoid of inflexion point. This phenomenon is difficult to explain on the grounds of deterministic building physics. It may be explained, however, on the grounds of structural reliability theory, and in particular well known problem of serial or parallel reliability models of non renewable structures. The single chamber Polflam glass panes, regardless of the swelling gel layer thickness, constitute a link of serial system in the partition. However, addition of composite glass pane chambers changes the system into a serial one. Such interpretation has been predicted by qualitative and quantitative evaluation of system glass-aluminum partitions subjected to fire conditions, conducted by the author in paper [5]. Hence the general postulate that the design of building fireproof partitions should take into account the results of reliability models of non-renewable systems. The $\Delta T(t)$ temperature increase characteristic of aluminum sections is in each of the considered cases the same, as these curves exhibit an inflexion point changing location depending on the total thickness of thermal insulation, cf. Fig. 6 and Fig. 7. Due to practical considerations, in order to simplify the interpretation of the results of numerous fire resistance tests performed during attestation of glass-aluminum partitions, linearization of $\Delta T(t)$ characteristics, and collective presentation of results as shown in Fig. 10 and Fig. 11 is suggested. The fire resistance test of a partition is positive in each case where the linear functions do not cross the limit value (horizontal line $\Delta T/T_{ult} = 1.0$). Fire resistance attestation of system partitions constitutes an important component of national experimental and theoretical [3–5] research in the standardization domain of calculations of glass-aluminum structures which are conducted in Europe as a part of the work of the European Committee for Standardization (CEN) [1, 2].

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Badania odporności ogniowej przegród aluminiowo-szklanych

Słowa kluczowe: aluminium, pożar, odporność ogniowa, szkło, przegrody, testy laboratoryjne

Streszczenie:

Fasady aluminiowo-szklane budynków, a także przeszklone ścianki działowe przeznaczone do konstruowania różnego rodzaju przegród wewnętrznych z drzwiami szklanymi, których zadaniem jest wydzielenie stref pożarowych, muszą spełniać określone w przepisach wymagania odporności pożarowej. W ofercie producentów krajowych i zagranicznych systemowe przegrody ogniochronne są wytwarzane w klasach odporności ogniowej od EI 30 do EI 180. Właściwości ogniochronne takich przegród są badane laboratoryjnie, a wyniki testów ogniowych stanowią podstawę wydawanych aprobat technicznych. W artykule przedstawiono wyniki badań ogniowych wybranych przegród, wiodącego krajowego producenta systemów aluminiowo-szklanych, które są reprezentatywne dla całej oferty handlowej firmy Aluprof S.A. Przeprowadzone w procesie atestacji laboratoryjne próby ogniowe były realizowane przez trzy niezależne od producenta, akredytowane laboratoria badawcze, Badano odporność ogniową drzwi i przegród uformowanych z profili aluminiowych z izolacją ogniową w jednej lub kilku komorach oraz szyb Polflam o zróżnicowanej grubości żelu pęczniejącego. Wyniki badań w pełni potwierdziły deklarowaną w specyfikacjach zakładowych odporność pożarową systemowych drzwi i przegród o symbolach katalogowych MB-78EI oraz MB-118EI. W artykule przeprowadzono analizę porównawczą krzywych przyrostu temperatury na zewnętrznej powierzchni szyb i profili aluminiowych, z których uformowano badane przegrody. Wskazano na związki pomiędzy konstrukcją profili i szyb ogniochronnych, a kształtem krzywych empirycznych. Zaproponowano linearyzację mieszaną styczno-sieczną licznych tych krzywych oraz prezentację wyników badań ogniowych we współrzędnych bezwymiarowych. Taka forma prezentacji końcowych wyników badań ognioodporności pozwala na czytelną interpretację testów laboratoryjnych z wiarygodnym udokumentowaniem nominalnych wymagań odporności ogniowej.

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