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ALUMINIUM IN OFFSHORE CONSTRUCTIONS: FIREPROTECTION.	1983-05-30
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EKSTRAKT

Due to the low melting temperature of aluminium (650 °C) special considerations have to be taken when using aluminium in fire hazard areas.

Classes and criteria are defined and possible use of aluminium is mentioned.

Further, results from standardized tests, real fire incidents and classified constructions are examined.

Finally, design of aluminium vs. steel according to NS 3478 are showed through an example.

3 STIKKORD

Aluminium	Aluminium
Offshore constructions	Offshore konstruksjoner
Fire resistance	Brannmotstand

CONTENTS

SUMMARY

Due to the relative low melting temperature of aluminium, (650 - 660°C), and that most aluminium alloys have lost half their capasity at a temperature level of 250°C, it is obvious that aluminium structures must be insulated in order to meet the offshore fire regulations.

The different classes are defined, and how the class of a construction can be determined through a standardized fire test. The background of using aluminium instead of steel offshore, are among others the high strength to weight ratio, good resistance to corrosion and reduced costs connected to surface treatment. However, to defend the use, the insulated aluminium structure must not be heavier than the similar insulated steel structure, and the capasity must be the same after the prescribed fire exposure. Aluminium can replace steel in decks, bulkheads, structures etc., and examples of classified aluminium constructions are mentioned.

When it comes to fire incidents where aluminium has participated as a building material, the available litterature are insufficient. In most of the incidents unprotected aluminium was exposed to the fire, and this will of course give an unfortunate view of the material. Reports from fires where insulated aluminium has taken place have not been found, and it is therefore difficult to say how these constructions will behave in a fire situation.

In the fields where aluminium probably can replace steel as a structural material, a number of classified steel constructions are listed.

Finally it is shown how fire exposed aluminium structures can be designed according to NS 3478.

1. INTRODUCTION

1.1 Passive Fire Protection; general

Most of the construction materials used will loose strength when heated to temperatures occuring in a fire. Wood actually burns with decreasing cross sections as a result, metals will get lower yield stress and concrete looses strength due to spalling (decrease of cross section) and lower yield stress in the reinforcement. Metals as steel and aluminium alloys will also expand when heated, with buckling of the construction as a possible result.

The figures underneath show the yield stresses and E-modules for some steel and aluminium alloys as a function of temperature.

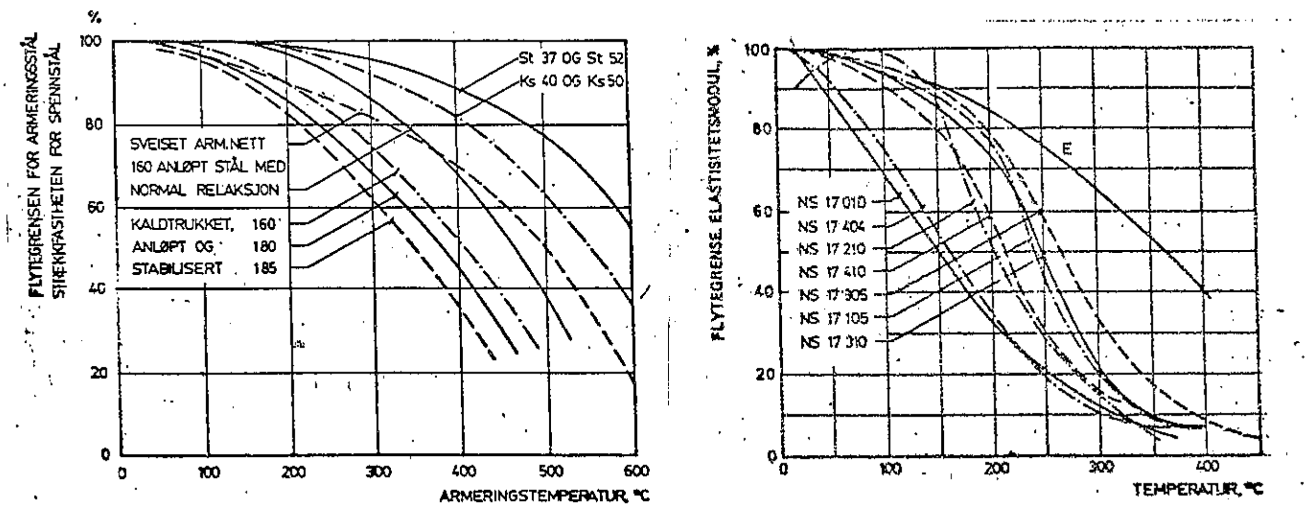


Fig. 1.1 a) Yield stress/tensile strength for different reinforcement steel as a function of temperature.
b) Aluminium alloys; yield stress and E-module as a function of temperature. (1)

The figures show that some steel have lost half the strength at a temperature of 500°C. For most aluminium alloys this reduction is reached already at a temperature of 250°C. When we know that these temperatures are reached within a short time during a fire, it is obvious that some protection is needed.

Protection of constructions against fire can either be socalled "active" or "passive". Active fire protection concerns what can be done to protect against a fire when it actually occurs; i.e. activation of sprinkler equipment, fire fighting etc. Passive fire protection concerns what is done to prolonge the fire resistance of a construction before an eventual fire occurs. Examples can be insulation of structures, choise of incombustible materials, use of fireresistant partions and fire sectioning in order to prevent the spread of a fire etc.

For loaded structures the bearing capacity during the actual fire (both heating- and cooling period) must not be less than the value which gives a reasonable security against collapse at the given load. This requirement gives a critical temperature of the material used in the structure. (Previous figures).

For fire resistant partitions the functional requirements concist partly of a demand of tightness against penetration of flames, and partly - for some types of partitions - a demand of temperature restrictions on the side of the construction facing away from the fire. Materials used as insulation offshore must: (2)

- have good performance under fire conditions,
- be easy to apply,
- not present any health hazard,
- have long effective life under the environmental conditions. (Materials should be selected according to the conditions; inside or outside).

1.2 Fire models

The most common model used for classification of building constructions, is a fire following the ISO timetemperature curve. This curve is defined by the equation

$$T - T_o = 345 \log_{10} (8 t + 1)$$

where T = temperature at time t
T_o = temperature at time $t = 0$
t = time in minutes from start of fire

This fire model is based on a fire load mostly consisting of wood.

The development of the activities offshore has required a new and more severe fire model. Temperatures in hydrocarbon fires, (which are possible on ofshore structures,) will increase much faster and reach a higher level than fires based on a fire load of wood. Little work is done to get to know what happens in a hydrocarbon fire, and there is not yet any standardized test to evaluate the resistance of constructions exposed to such a fire.

Two models are suggested for a hydrocarbon fire: "BP-curve" and "Mobil/NPD-curve".

In lack of any better documented models, the Mobil/NPD-curve is followed in tests performed in Norway. In the diagram below the three different time-temperature curves are shown.

The ISO-curve is drawn as a temperature rise, but BP' and Mobil/NPD show the actual temperature.

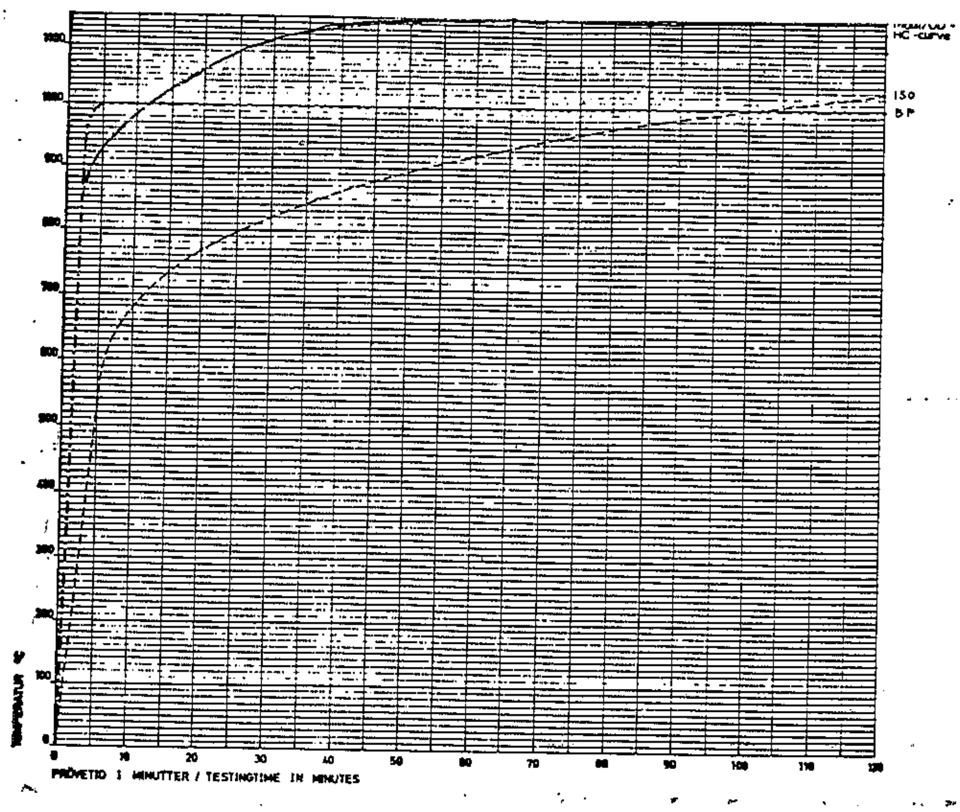


Fig. 1.2 Different time-temperature curves.

2. CLASSES AND CRITERIA

Different constructions can be classified according to their resistance against fire exposure. With resistance is meant that the construction must maintain integrity, stability and the prescribed insulation value within the given classification time.

Fire resistance of constructions used in offshore constructions, is divided into three main classes: A-, B- and H-. A- and B-constructions are tested against a fire exposure following the ISO-curve, and H- constructions are tested against a fire exposure following the Mobil/OD-curve for hydrocarbon fires (H means hydrocarbon). After the letter comes a number (-10, -15, -30 etc.) which is indicating the time in minutes the construction is resistant according to the given fire class.

On the Norwegian continental shelf there are small differences between fixed and floating platforms in classification criteria. Constructions on board fixed platforms are subject to the rules given by the Norwegian Petroleum Directorate (NPD), and constructions on board floating platforms are subject to the rules given by the Norwegian Maritime Directorate (NMD).

NMD uses the rules given in SOLAS- (Safety of Life at Sea) convention, and NPD uses their own rules "Regulation for Production- and Auxiliary Systems on Production Installations etc." The rules given in SOLAS are much more spesific than the NPD-rules, and in this report the main difference is shown when it comes to the use of aluminium alloys in stead of steel.

When it comes to H-class constructions, only NPD has this mentioned in their rules.

2.1 A-class partitions

An A-classification can be given to bulkheads, decks, doors and frames.

The partitions shall be made of steel or equivalent material. They shall prevent flames and smoke from advancing for a minimum of 60 minutes as per standardized test. The partitions shall be insulated with non-combustible materials so that the average temperature on the side not being exposed to fire, does not exceed 139°C (250°F) above the initial temperature and the temperature shall not at any place exceed 180°C (325°F) above the initial temperature within the time limit given below:

Class A-60	60 minutes
Class A-30	30 minutes
Class A-15	15 minutes
Class A-0	0 minutes

For an A-class bulkhead or deck test specimen, the NMD prescribes the dimensions of an structural core. A-class doors and frames have to be mounted in such a core.

Bulkheads

Thickness of plating:	Steel:	4,5 ± 0,5 mm
	Al:	6.0 ± 0,5 mm
Vertical stiffeners spaced at 600 mm:	Steel:	65 ± 5 x 65 ± 5 x 6 ± 1 mm
	Al:	100 ± 5 x 75 ± 5 x 9 ± 1 mm

Decks

Thickness of plating:	Steel:	4,5 ± 0,5 mm
	Al:	6,0 ± 0,5 mm

Vertical stiffeners spaced at 600 mm:	Steel:	100 ± 5 x 70 ± 5 x 8 ± 1 mm
	Al:	150 ± 5 x 100 ± 5 x 9 ± 1 mm

In the case of load-bearing divisions of aluminium alloy, the average temperature of the structural core shall not rise more than 200°C above its initial temperature at any time during the test for one hour.

An unisulated steel partition meets the A-0 criteria, an uninsulated aluminium alloy partition does not meet the requirements for A-class divisions.

2.2 B-class partition

A B-classification can be given to bulkheads, decks, ceilings, doors and frames.

The partitions shall be made of non-combustible materials and shall prevent flames from advancing for 30 minutes as per standardized test. The partitions shall be insulated in such a way that the average temperature on the side not being exposed, does not exceed 139°C (250°F) above the initial temperature and shall not at any place exceed 225°C (435°F) above the initial temperature within the time limit given below:

Class B-30	30 minutes
Class B-15	15 minutes
Class B-0	0 minutes

For a B-class deck NMD prescribes the following:

The structural core of the test specimen shall be of aluminium alloy having scantlings:

Thickness of plating:	6,0 ± 0,5 mm
Deck beams spaced at 600 mm:	(150 ± 5) x 100 ± 5 x 9 ± 1 mm

NB! In the case of load-bearing divisions of aluminium alloy the average temperature of the structural core shall not rise more than 200°C above its initial temperature at any time during the test for one half hour.

2.3 H-class partitions

Only NPD has defined requirements for H-class partitions.

The partitions shall be made of non-combustible materials. Any insulation material shall be tested by a recognized institution. The partition shall maintain its function with respect to fire resistance and structural integrity for two hours when exposed to a heat load characteristic for a hydrocarbon fire.

The partitions shall be insulated in such a way that the average temperature on the side not being exposed does not exceed 139°C (250°F) above the initial temperature and the temperature shall not at any place exceed 180°C (325°F) above the initial temperature within the limit given below.

Class H-120	120 minutes
Class H-60	60 minutes
Class H-0	0 minutes

Standardized test procedures for this type of partition do not exist.

Because of the severe thermal stress it is not likely to believe that an aluminium alloy construction can compensate one made from steel.

When it comes to load-bearing structures, only A- and H-class are reasonable on offshore structures. In both classes only non-combustible materials should be used. A-class structures are tested against a fire following the ISO-curve, and the H-class structures are tested against a fire following the Mobil/NPD-curve.

After the letter A- og H- comes a number which gives the resistance time in minutes. Within this time the temperature of the structure (when it comes to metals) shall not exceed a given critical temperature due to the yield stress loss as a function of temperature. For aluminium this $T_{crit.}$ is suggested to be $200^{o}C$ depending on the alloy.

In "Regulations for the structural design of fixed structures on the Norwegian Continental Shelf", given by the Norwegian Petroleum Directorate in 1977, the accidental load "fire" is mentioned two places.

Point 2.1 "Structures and structural elements shall be designed to maintain adequate stability and resistance in case of fire during a spesified period."

Point 3.6 "Change in material properties caused by fire shall be accounted for in the assessment of resistance.

3. DETERMINATION OF A-, B- AND H-CLASSES

A- and B-class constructions and structures are determinated through standardized tests (according to IMO Res. A 163) against furnaces heated in accordance with the ISO time-temperature curve. H-class tests are not yet standardized, but orientating tests similar to those run for A- and B- can be performed in order to get H-classification. The test furnace is then heated according to Mobil/NPD's hydrocarbon time temperature curve.

To determine A- and B-classification a furnace with horizontal or vertical exposure opening is used due to the orientation the partition has in the real construction.

At the Norwegian Fire Research Laboratory the exposure openings of the horisontal and the vertical furnace are 5,0 x 2,5 m^2 and 3,0 x 2,5 m^2 respectively. Both depths are 1,5 m.

The pilot furnace used for testing against hydrocarbon fires has inner dimensions 1,0 x 1,0 x 1,0 m and can be used with both vertical and horisontal exposure opening.

4. SOME PHYSICAL PROPERTIES OF ALUMINIUM

Solid aluminium used as a building material is non-combustible. Only when apearing as powder or filings aluminium can oxydize similar to a fire.

Underneath are listed some properties of solid aluminium. (6), (16)

Ignition temperature in pure oxygen:	$T_i > 1000^\circ C$
Thermal conductivity:	$\lambda = 200 - 230\ W/m^\circ C$ (4 times the λ of steel)
Coefficient of thermal elongation for the range 20 - 100°C:	$\alpha = 24 \cdot 10^{-6}/^\circ C$ (twice the α of steel)
Intervall of melting:	650 - 660°C (steel 1450 - 1540°C)
Melting point:	T_m = ca. 650°C
Spesific melting heat:	$q_m = 388$ kJ/kg
Density:	$\rho = 2700\ kg/m^3$ (1/3 of steel)
Spesific heat capasity:	$c_p = f(T)$ see table

T	0	100	200	300	400	500	°C
c_p	0,92	0,96	0,99	1,02	1,05	1,09	kJ/kg°C

Tensile strength σ_B, yield stress $\sigma_{0,2}$ and modulus of elasticity E as functions of temperature for some alloys are shown in the figure below. (Same figure as in Introduction)

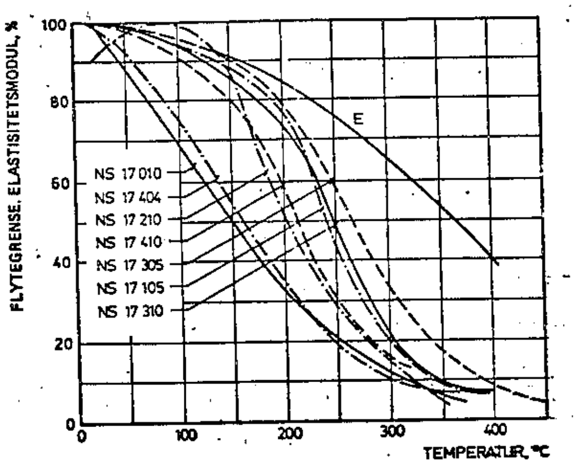


Fig. 3.1 σ_B, $\sigma_{0,2}$ and E for some Al-alloys as a function of temperature.

From these physical properties it can be seen:

- due to the relative high thermal conductivity of aluminium, heat will easily be lead away from the exposed area. This will slow the heating, but will also cause a temperature rise in the adjacent areas.

- heat capasity is twice the value of steel, i.e. more energi is needed to rise the temperature in one kilo aluminium one ^{o}C than in one kilo of steel. In most cases this is compensated for by the lower density of aluminium.

- Most Al-alloys have lost their strength at material temperatures higher than 350^{o}C.

Another aspect with aluminium at high temperatures is that liquid aluminium in contact with water can cause explosions. The explosive force of instantaneous steam production when molten metal is mixed with water is well known. Foundry personell can testify to the severe burns which may be sustained as a result of such incidents and doubtless anyone exposed to a fire in which aluminium components melt would suffer similarly. (12)

5. FIELDS ON A OFFSHORE CONSTRUCTION WHERE ALUMINIUM ALLOYS CAN BE COMPETATIVE TO STEEL

The most important reason why it is considered to use aluminium alloys in offshore constructions is of course the possibility to save weight. Lightweight structures would make the mounting operations more easy, and less weight above the centre of gravity would improve the stability of the total construction.

Where fire exposure is possible, uninsulated aluminium structures (at least not bearing structures) must not be used.

To fullfill the intention by using aluminium, an insulated aluminium structure should not be heavier than the steel structure with equal strength and fire resistance.

Some fields where aluminium are used and have been consideres used are:

- Helidecks:
  * plating
  * beams

- Quarter modules:
  * bulkheads
  * decks
  * ceilings

- Other constructions:
  * derricks
  * towers
  * bridges
  * flare booms
  * gangways
  * ladders
  * stairsteps
  * beams/columns

Gangways, ladders and stairsteps used for escape and emergency exits ought to have good fire resistance, and it is therefore doubtful that aluminium could replace steel in these constructions.

6. RESULTS FROM STANDARDIZED TESTS AND OTHER FIRETESTS ON ALUMINIUM CONSTRUCTIONS

At the Norwegian Fire Research Laboratory very few tests have been carried out on insulated aluminium constructions. In order to publish these results, the customers allowance has to be achieved.

The classified constructions mentioned in this chapter are taken from "List of Equipment Approved by the Norwegian Maritime Directorate".

6.1 Aluminium deck constructions

6.1.1 A-60 dekk

Manufactured by Grünzweig & Hartmann und Glasfaser AG, Germany.

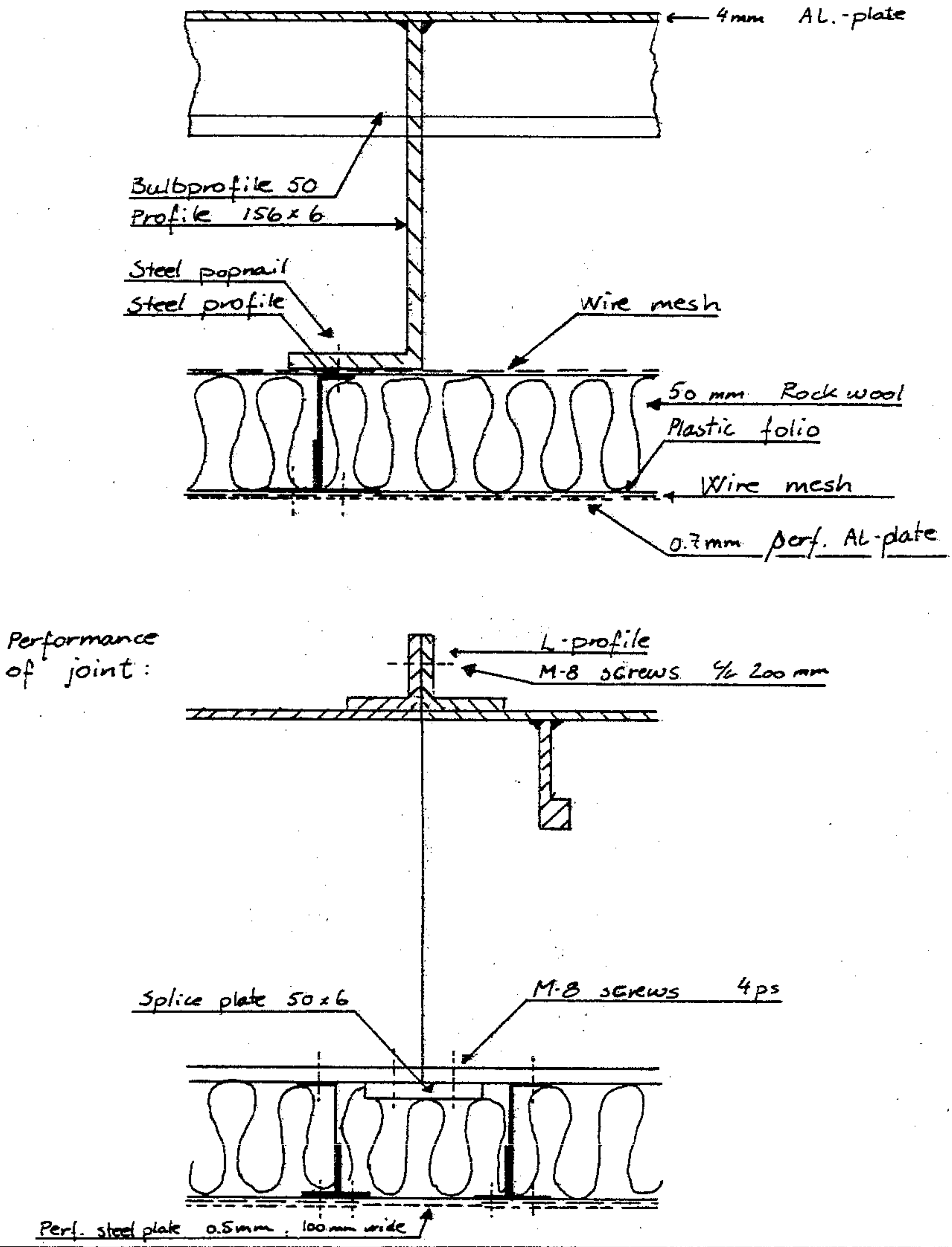
The structural core is made of 8 mm stiffened aluminium plate. The underside of the deck, included the stiffeners, is insulated with 50 mm Isover. Mineralfasermatte MDD/TR 125 with a density of 125 kg/m^3.

6.1.2 Fire test on aluminium deck

This next deck was tested at the Norwegian Fire Research Laboratory.

The testing object was built up of two aluminium deck elements with dimensions 2800 x 2800 x 210 mm and 2800 x 2500 x 210 mm, connected by means of screws and a joint element with insulation. See figure 6.1.

Aluminium deck construction
Insulation: 50 mm Rockwool 110 kg/m^3



Dato	Konstr./Tegnet	Tracet	Målestokk	
83-05-30	U.D.		1:2.5	FIG 6.1
Kontroll	Stand.kontroll	Godkjent		

Aluminium deck construction insulated with 50 mm Rockwool.

Erstatning for:	Erstattet av:

Henvisning:	Beregning:	

The construction consisted of 4 mm aluminium plating with L--shaped aluminium stiffeners 156 x 6 mm c/c 600 mm. To these stiffeners were mounted steel profiles by means of rivets. Between these profiles were 50 mm Rockwool 110 held in place with a mesh on both top and bottom. Under the bottom mesh was a 0,7 mm perforated Al-plate.

This construction was tested according to IMO Res. A 163 and the ISO time-temperature curve.

To satisfy the criterion of an A-class deck construction there shall be no penetration of flames during 60 minutes of testing time. In this case this happened after 53 minutes.

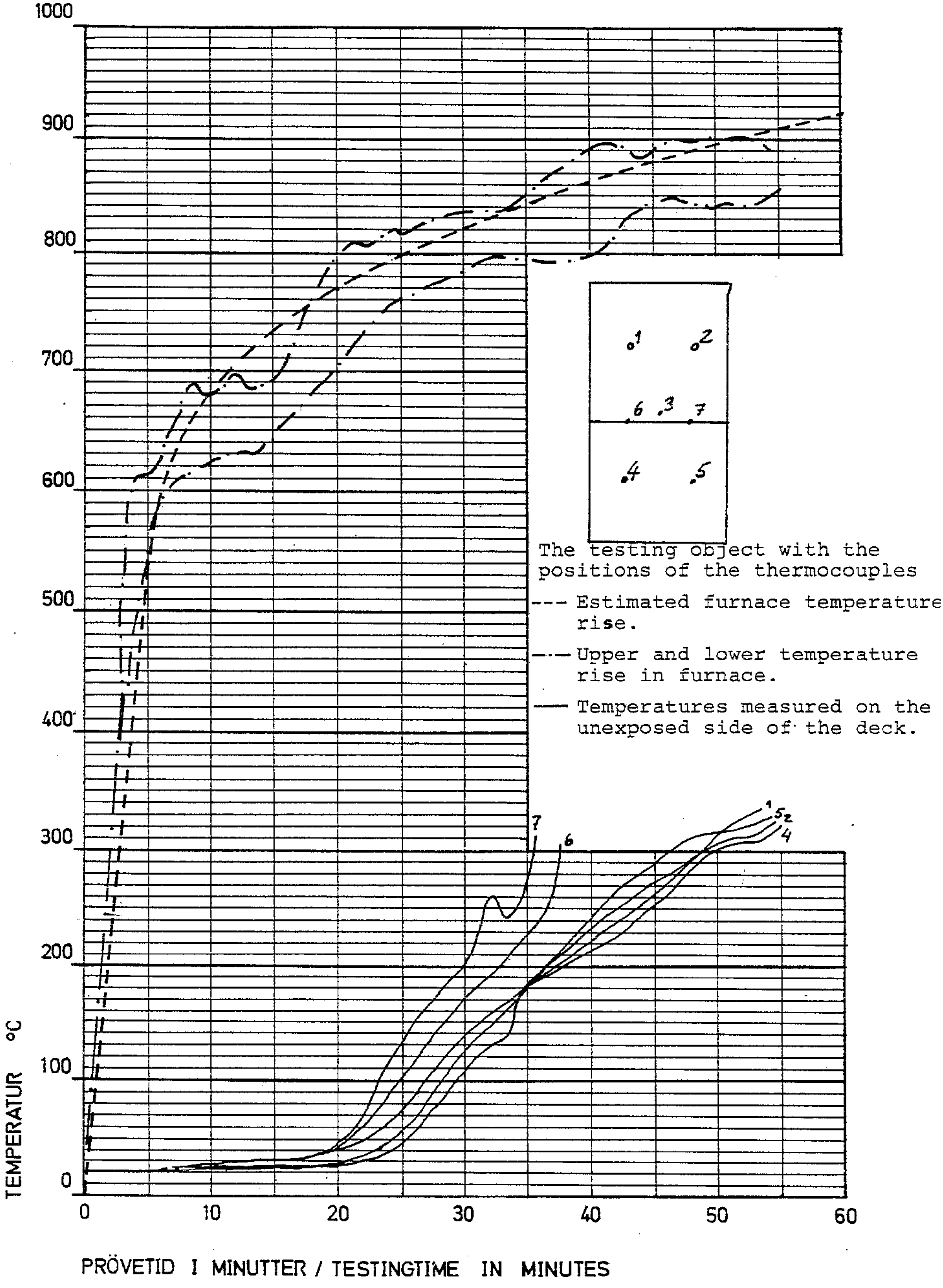
After 20 minutes the perforated aluminium plate on the underside (exposed side) of the deck had mainly melted away. After 35 minutes the insulation cassette at the joint (the joint element; see fig. 6.1) had fallen down.

After app. 50 minutes the aluminium profiles near the joint started to melt, and three minutes later the 4 mm aluminium deck plate started to melt from the joint and flame penetration occured.

On the enclosed time-temperature sheet the positions of the thermocouples and the temperatures are shown.

The allowed maximum temperature rise of 180^{o}C was exceeded after 30 minutes, while an average temperature rise of 139^{o}C was reached after 33 minutes.

The conclusion on this report was that to make this construction more fire resistant, it seemed necessary to use a better wire netting and to perform an eventual joint in a better way.



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PRÖVETID I MINUTTER / TESTINGTIME IN MINUTES
1
2
6
3
7
4
5
The testing object with the positions of the thermocouples
--- Estimated furnace temperature rise.
-·- Upper and lower temperature rise in furnace.
— Temperatures measured on the unexposed side of the deck.

FIG 6.2

6.2 Aluminium bulkhead constructions

6.2.1 A-60 bulkheads

* Manufactured by Dansk Eternit-Fabrik A/S, Denmark.

The bulkhead is built up of an aluminium core (dimensions not mentioned) insulated on both sides with 16 mm (5/8 inch) Navilite boards. The minimum distance between the aluminium and the Navilite boards should be 19 mm (3/4 inch). The construction is only approved as a non-bearing bulkhead.

* Manufactured by Dansk Eternit-Fabrik A/S, Denmark.

Same construction as above, but 22 mm (7/8 inch) Navilite boards instead of 16 mm.

* Manufactured by Deutsche Rockwool.

The bulkhead is built up of a structural core of aluminium (no dimension mentioned) insulated on both sides with 50 mm Rockwool Brandplatte RPB with a density of 100 kg/m^3.

* Manufactured by Flumisol, France.

A bulkhead bult up of a structural core of a 8 mm aluminium plate insulated on both sides with 50 mm Isover firebatts MDD/TR with a density of 125 kg/m^3.

* Manufactured by Marinite Ltd. England.
(Dealer A/S Astral, Oslo)

An aluminium bulkhead insulated on both sides with 19 mm (3/4 inch) Marinite. The minimum distance between the bulkhead and insulation is 25 mm (1 inch).

* Roclaine S.A., France

An aluminium bulkhead insulated on both sides with 50 mm (2 inches) Rocklaine 643 (BX Spintex) rockwool with a density of 96 kg/m^3. The bulkhead is only approved as a non-bearing bulkhead.

* A/S Rockwool, Codanhus, Denmark.

An aluminium bulkhead insulated on both sides with 50 mm (2 inches) Rockwool and 40 mm (1½ inches) Rockwool over stiffeners. Density 107 kg/m^3. The bulkhead is only approved as a non--bearing construction.
If using 65 mm and 40 mm Rockwool Firebatts (density 100 kg/m^3) over plate and stiffeners respectively, the construction is approved as a bearing bulkhead.

* Turners Asbestos Cement Co., England

An aluminium bulkhead insulated on both sides with 19 mm (3/4 inch) Turnall Asbestos Ships Board with density 580 kg/m^3 (36 lbs/ft^3). The distance between the bulkhead and the board should be 100 mm (4 inches) on the stiffened side and 25 mm (1 inch) on the plane side.

When using 13 mm (½ inch) boards and distances to the bulkhead 98 mm (1 7/8 inches) and 22 mm (7/8 inch) respectively, the bulkhead has approval as a non-bearing construction only.

6.2.2 A-30 bulkhead

* Turners Asbestos Cement Co., England

Same as the non-bearing bulkhead mentioned above. The bulkhead is approved as an A-30 load-bearing construction.

6.2.3 Fire test on aluminium bulkhead

The following test was performed at the Norwegian Fire Research Laboratory.

The bulkhead was made of a 4 mm stiffened aluminium plate insulated on the stiffener side with 19 mm Kaowool ceramic fibre. Fig. 6.3 shows the construction of the bulkhead.

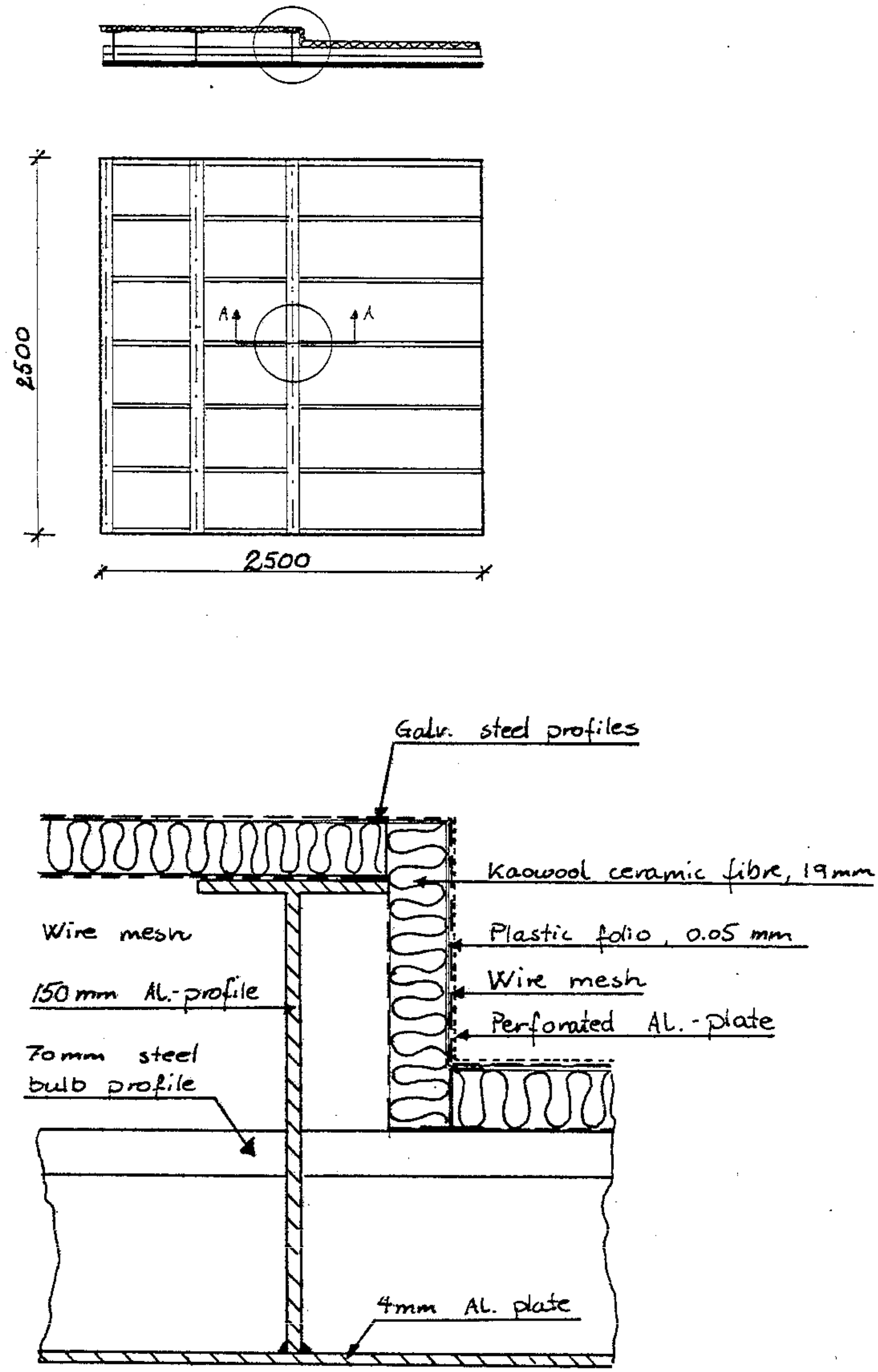
The bulkhead construction was mounted with the insulated side against the exposure opening of the vertical test furnace. The furnace was heated according to the ISO curve, and temperatures measured on the unexposed side of the test object by means of seven thermocouples. Their positions are shown on the sketch on the time temperature sheet in fig. 6.4.

After 10 minutes testing time the perforated aluminium plate on the exposed side had melted. After 22 minutes the mesh on exposed side of the insulation is partly damaged. The test was stopped after 60 minutes.

The time-temperature curves show that maximum temperature rise of 180^{o}C was reached after 24 minutes. Allowed mean temperature rise of 139^{o}C was reached after app. 23 minutes. This construction did not satisfy the criteria of an A-30 bulkhead.

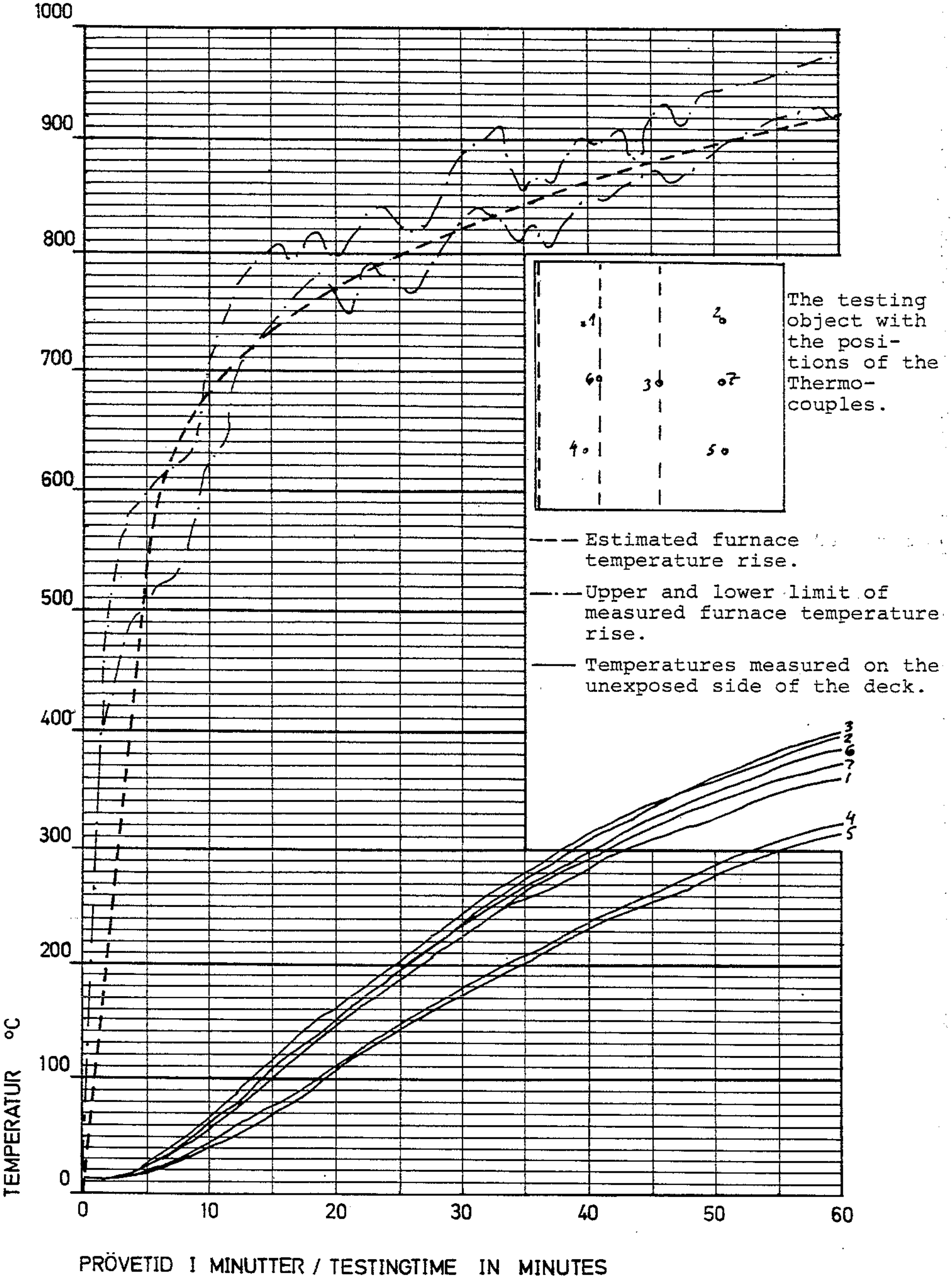
6.3 Aluminium doors

When it comes to doors, it must be made clear that there are great differences in the criteria offshore and onshore. The offshore criteria are the same as for divisions (mean temperature rise of 139^{o}C and maximum rise of 180^{o}C), but onshore the criteria of mean temperature rise of 280^{o}C and maximum rise of 330^{o}C are used for A-class doors.



Dato 83-05-30	Konstr./Tegnet U.D.	Tracet	Målestokk 1 : 2	FIG 6.3
Kontroll	Stand.kontroll	Godkjent		

Insulated aluminium bulkhead.	Erstatning for:	Erstattet av:
Henvisning:	Beregning:	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TEMPERATUR °C
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PRÖVETID I MINUTTER / TESTINGTIME IN MINUTES
The testing object with the positions of the Thermo-couples.
Estimated furnace temperature rise.
Upper and lower limit of measured furnace temperature rise.
Temperatures measured on the unexposed side of the deck.

FIG 6.4

A number of doors made of extruded aluminium profiles are classified as A-60 and A-30 doors according to the onshore regulations, but none are found to fullfill the offshore regulations.

As an example (test at the laboratory) can be mentioned that a single aluminium door with an onshore A-60 type approval would have failed the offshore criteria for divisions after ca. 30 minutes.

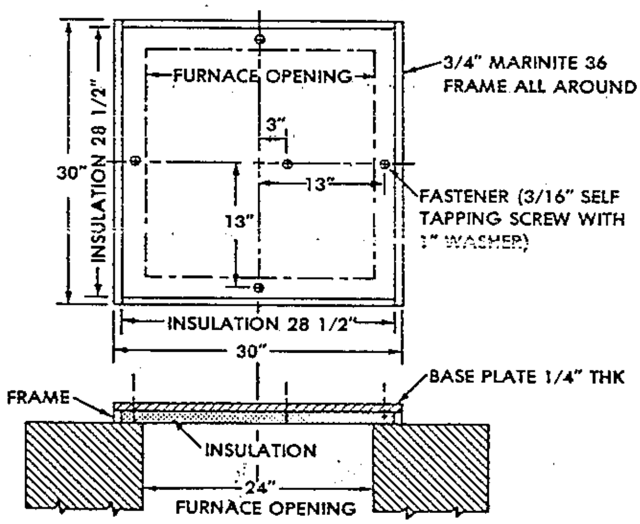
An A-30 type approved double aluminium door would have failed after 12 minutes.

In the lists of type approved equipment from NMD and DnV no aluminium doors have been given A-classification.

6.4 Small scale testing of bulkheads

In (11) is described a project which was carried out to evaluate the difference in performance between a number of insulation materials.

The different materials were used to insulate aluminium bulkheads, and the constructions were tested on a gas heated furnace as shown in figure 6.5 below.



Panel Detail and Relationship to Furnace.

Fig. 6.5 Panel detail and relationship to furnace.

The tests were performed without any mechanical loading of the testing object.

The purpose of the test described here was to screen candicate lightweight insulations to protect aluminium structures against fire.

Since aluminium has lost half its strength at 230°C (450°F), this temperature was established as the failure point for the small-scale fire endurance tests.

As insulation both homogenous and composite systems were choosen. See table.

insulation	density (kg/m^3)
mineral wool	96
refractory felt	65
refractory blanket	65
refractory felt	96
refractory blanket	96
Polyisocyanurate foam	40
Polyisocyanurate foam	60
Polyimide foam	65

composites:

PIR foam with outer layer of refractory felt.
Polyimid foam with outer layer of refractory felt.
PIR foam with outer layer of mineral wool.

Temperatures on the unexposed side were measured by means of thermocouples. Their positions are showed in fig. 6.6 below.

THERMOCOUPLE LOCATIONS

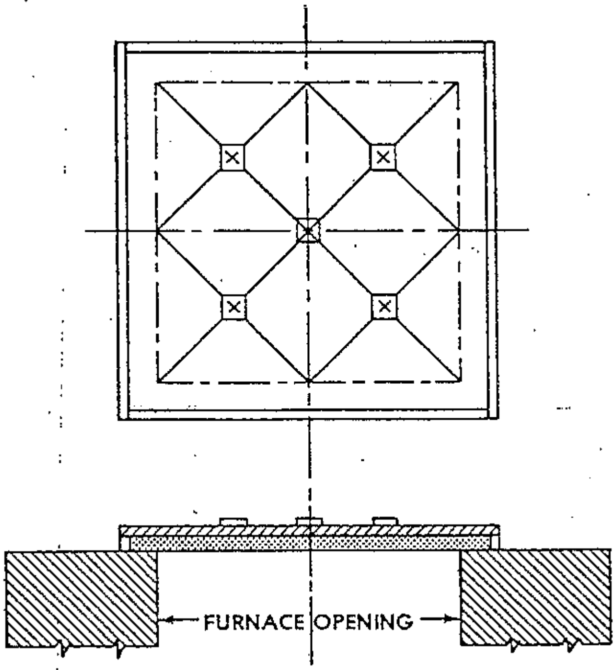


Fig. 6.6 Positioning of thermocouples on unexposed side of the object.

The testing showed that the foams alone shrank and ignited, with a rapid temperature rise on unexposed side as result. A protection of these foams with a refractory felt or mineral wool improved the construction. However, HCN-gas emitted from the PIR foam upon heating and ignition.

The tests also showed that 45 mm of 65 kg/m^3 refractory felt will offer about the same protection as 75 mm of 96 kg/m^3 mineral wool for equal time periods up to one hour duration. If this proves to be a valid assuption, a saving of more than 4 kg per square meter may be realized. It is noted, however, that this information was obtained from the testing of small scale samples.

Underneath are showed temperatures on unexposed side of the different insulated samples.

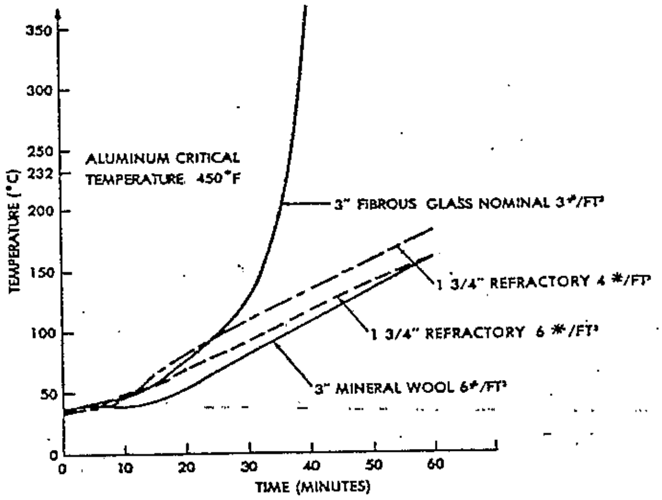


Fig. 6.7 Recorded temperatures on unexposed side of 6,5 mm aluminium base plate insulated on fire side.

7. PRACTICAL EXPERIENCES FROM FIRE INCIDENTS WHERE ALUMINIUM CONSTRUCTIONS HAVE TAKEN PLACE

It must be said that very little litterature have been found when it comes to the role aluminium plays in an actual fire. When aluminium is mentioned at all, it is only said with a few words that aluminium has melted.

7.1 Fire incidents onshore

(13) is an article about light ceilings and fire risks in general. The author is concerned about the relatively low fire resitance these ceiling constructions are able to give. However, he is also mentioning that the relatively low melting point of aluminium can be utilized. A fire can be vented through a melted aluminium ceiling construction in stead of through smoke hatches. Such a fire venting can however be delayd if the ceiling is covered with ice and snow. The apprance of snow and ice will delay the melting of aluminium.

The use of aluminium on greater areas of a ceiling could cause danger to the fire fighters in a fire. Molten aluminium at a temperature of 650°C can without doubt cause injuries even as small drops. Both fire venting and the hazard with molten metal are also mentioned in (14). This report is also listing a number of fires where aluminium has been involved or at least been mentioned.

Fires in a school, a warehouse, a generator station and a society building all lead to melting of aluminium used as claddings on walls and ceilings. Nothing was said if the appearance of aluminium endangered the hazard. In the generator station the fire caused a rapid melting of the aluminium roof and smoke and flames were vented out. The early collapse of the aluminium roof did much, it was said, to reduce lateral spread of the fire and made conditions for the fire fighters less arduous.

The report is also mentioning a fire in a railway wagon containing shavings of aluminium and alloys. The fire was stated to have been caused by spontaneous combustion.

7.2 Fire incidents offshore

(14) reports two fire incidents where aluminium has taken place. The first was a fire on board a passenger ferry boat. A fire started on the bridge. The bridge was made of aluminium, and the walls near the fire melted. There was no comments about any influence of aluminium on the fire.

The other case was a fire in a naval frigate in dry dock. The superstructure was made of aluminium alloy. A fire broke out, cause unknown, and there was a rapid spread, due to the failure of the aluminium structure to confine the fire to its initial zone and ample supply of fresh air through openings in the superstructure. The extensive heat conduction through aluminium also caused buckling in many places clear of the fire zones.

(11) is mentioning four events where boats more or less constructed in aluminium have been exposed to a fire.

An engine room fire on an aluminium pusher vessel raged out of control. As a result, the operator abandoned ship and watched his ship slowly melt.

In an offshore drilling area in the Far East, four aluminium hull crew boats (just under 24 tons) were exposed to an AVGAS spill in the harbor. After the fuel ignited, the boats attempted to escape from the area. Two boats were completely destroyed in this fire, a third was severely damaged while the fourth managed to escape with relatively minor damage.

A fire was reported aboard an aircraft carrier in which an entire aluminium bulkhead had melted, leaving only the steel door frame intact.

The last incident mentioned was a fire in an aluminium hydrofoil caused by a hydraulic leak. Extensive damage to the craft's primary structures quickly followed.

Perhaps the latest and most known examples of fire and aluminium are from the war at the Falkland Islands in 1982 (15). Four English warships were sunk, and numerous newspaper articles after the war blamed the use of aluminium in the superstructures of the boats. The articles were very subjective and many statements concerning the properties of aluminium were even wrong.

(15) is in fact a paper trying to defend the use of aluminium.

Most of these examples are not very relevant to what this report actually concerns; aluminium in offshore constructions. All the examples describes events where unprotected aluminium has been exposed to a fire. It is well known that aluminium melts at a relative low temperature, and the results from the mentioned fire incidents are not very surprising.

Where aluminium alloys are going bo be used in offshore constructions, they have to be protected, likewise steel, if there is a possibility of fire in the area. Unfortunately no examples of fire incidents where insulated aluminium have participated, are found.

8. EXAMPLES OF FIRE CLASSIFIED CONSTRUCTIONS IN STEEL

The following constructions are taken from

* "List of equipment approved by the Norwegian Maritime Directorate" 1981 (9)
* "Type approved products. Fire restricting materials and fire technical equipment" (10)
* "Statlige byggebestemmelser" kap. 5.3
* Statens branninspeksjon: Approvals

Where there in the following tables is a * in the column named NOTES, it means that the Norwegian Fire Research Laboratory has the test report concerning the case. If there is an interest for some of these products, the Laboratory can contact the customers in order to try to release some of the information.

In some of the tables there are columns marked A/V max (m^{-1}).

A = surface area in m^2 per meter length of the construction. (m^2/m)

V = volume in m^3 per meter length of the construction (m^3/m)

"See report" in this column means that maximum A/V for each insulation thickness are given inthe approval certificate from "Statens branninspeksjon".

The products in the tables are only examples. Many more products could have been listed.

8.1 Structures with fire protective paints

Steel temperature: T_{s}, max = 500 °C

TRADE NAME	FIRM	A/V max	CLASSIFICATION	NOTES
UNITHERM	Ing. Nergaard Oslo	145 m^{-1} 290 m^{-1}	A-60 A-30	* *
PYROTECT S 30	Alveberg, Oslo		A-30	*

8.2 Structures with insulation board

Steel temperature: T_{s}, max = 500°C

TRADE NAME	FIRM	THICKNESS	A/V max	CLASSIFICATION	NOTES
VERMICULUX	NORCEM PLATER, NORWAY	20 mm	200 m^{-1}	A-30	*
		40 mm	200 m^{-1}	A-90	*
		55 mm	130 m^{-1}	A-180	*
VERMIT S	Ahlsell A/S, Oslo	see report	see report	up to A-120	*

8.3 Structures with sprayed insulation

Steel temperature T_{s}, max = 500°C

TRADE NAME	FIRM	THICKNESS	A/V	CLASSIFICATION	NOTES
COLLOSIL SMI	EKA KEMI, Sweden	30 mm	110 m^{-1}	A-90	
		50 mm	310 m^{-1}	A-60	
		70 mm	300 m^{-1}	A-120	
Albi-Duraspray	Alveberg A/S, Oslo	19 mm	165 m^{-1}	A-60	*
		38 mm	162 m^{-1}	A-120	*
CAFCO Blaze-Shield D C/F	A/S Ikas, Oslo	25 mm		up to A-240	
Pyrocrete 201	Star Carboline A/S, Drammen	9.5 mm	160 m^{-1}	A-60	*
		14.2 mm	162 m^{-1}	A-90	*
		19.0 mm	160 m^{-1}	A-120	*

8.4 Steel decks

TRADE NAME	PRODUCER	DESCRIPTION	CLASSIFICATION	NOTES
Akerpanel Ceiling Type B-300-2 + steel deck	Akerpanel A/S	Ceiling, 30 + 50 mm Rockwool underneath a steel deck acc. to IMO Res. A 163	A-60	*
Scanvi floating floor	Scanvi A/S	Steel deck, with 52 mm insulation cassettes on top	A-30	*
Scanvi floating floor	Scanvi A/S	Steel deck, with 70 mm insulation cassettes on top, in two layers á 35 mm. Joints covered by second layer.	A-60	* Evaluation based on A-30 test
Danacoustic continous ceiling	A/S ÅSV, Oslo	Ceiling, 12 + 25 mm Rockwool underneath steeldeck. Distance min. 300 mm.	A-30	
Steel deck + B-15 Panel	A/S ÅSV	Steel deck + B-15 panel	A-60	

8.5 Steel bulkheads

TRADE NAME	PRODUCER	DESCRIPTION	CLASSIFICATION	NOTES
Akerpanel D-600	Akerpanel A/S	Cassette insulation, 50 mm	B-15	*
Rocksil TR slab	A/S Teknisk Isolering	Steel bulkhead, insulated on both sides with 13 mm Rocksil TR Slab, 96 kg/m^3	A-60	
Rocksil TR slab	A/S Teknisk Isolering	Steel bulkhead, insulated on one side with 25 mm Rocksil TR Slab, 96 kg/m^3	A-30	
Akerpanel	Akerpanel A/S	Steel bulkhead, insulated with 50 mm cassettes (0.7 mm steel with Rockwool 150 kg/m^3 in between) min. 200 mm distance from the steel bulkhead	A-60	
Steel bulkhead	Alveberg A/S	Steel bulkhead insulated with 40 mm Jimoterm on both sides	A-60	

8.6 Steel columns

Steel temperature: $T_{s,\ max} = 500^{o}C$

TRADE NAME	FIRM	THICKNESS	A/V max	CLASSIFICATION	NOTES
Column A 60	Block Watne A/S	see report		A-60	*
Steel column casted in concrete	From "Statlige byggebestemm-elser"	table		50 mm A-180	

8.7 Ceilings

TRADE NAME	PRODUCER	DECSRIPTION	CLASSIFICATION	NOTES
Light Ceiling, Type Steel	A/S Lett-tak Syst. Larvik	Steel sheet, Rockwool, 0.7 mm steel + 12 mm plywood	A-60	*

9. ALUMINIUM CONSTRUCTIONS EXPOSED TO FIRE - DESIGN

9.1 NS 3478

The official method of designing constructions exposed to a fire hazard is given in the Norwegian Standard NS 3478. Tables and curves given for steel can also be used for aluminium when using a factor, due to different material properties, on the input data.

Input data in the design are

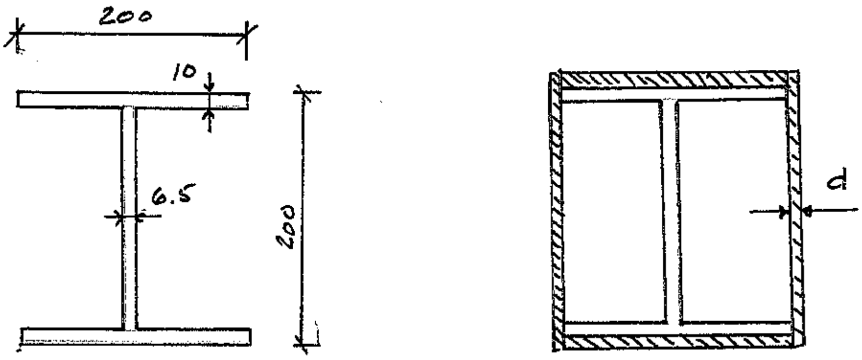
* duration of fire t	: given from fire load
* thermal conductivity	: insulation value
* A_s/V_s and A_i/V_s	: design of structure and insulation
* $T_{s,\ max}$ $T_{al,\ max}$	: maximum temperature
* ε_r	: emissivity, painted aluminium: ε_r = as for steel untreated aluminium: $\varepsilon_r = 0,3$

When designing aluminium structures, fig. 9 and table 11 in NS 3478 can be used by using $A_{al}/V_{al} \cdot \alpha$ or $A_i/V_{al} \cdot \alpha$ instead of A_s/V_s and A_i/V_s.

$$\alpha = \frac{c_{steel} \cdot \rho_{steel}}{c_{al} \cdot \rho_{al}} = \frac{0.52 \cdot 7.85}{0.92 \cdot 2.7} = 1.64$$

9.2 Example of aluminium vs. Steel designed according to NS 3478

To simplify the problem the same dimensions are used for both steel and aluminium:



uninsulated   insulated

Steel: Exposure: 18 minutes of ISO Fire.

We want to maintain 60% of the capasity $T_s < 450^oC$

$A_i/V_s = 150\ m^{-1}$
$t = 18$ min
$T_s < 450^oC$

} table 11 ⇒ $d_i/\lambda_i = 0.04$

Aluminium

Exposure: 18 minutes of ISO fire.

We want to maintain 60% of the capasity: (NS 17305)

$T_{al} < 250^oC$

$A_i/V_{al} = A_i/V_s \cdot 1.64 = 246\ m^{-1}$
$t = 18$ min
$T_{al}\ 250^oC$

} table 11 ⇓ $d_i/\lambda_i = 0.26$

In this example the insulation on the aluminium structure has to be more than 6 times thicker than the steel insulation to maintain the same capacity.

It must be said to the defence of aluminium that table 11 in NS 3478 is very conservative. It is not likely that a test would have given the same results.

At the end of the report, table 11 from NS 3478 is given as curves to simplify interpolation and extrapolation in design of insulated structures. Each curve is given an A_i/V_s-value. The numbers in paranthesis correspond to the A_i/V_{al}-values for aluminium (without the 1.64-factor).

10. CONCLUSIONS

Aluminium melts at a temperature level of 650 - 660°C, and most aluminium alloys have lost half their capasity at 250°C. (Fig. 2 in chapter 1.1). These temperatures are reached within few minutes in a fire. It is therefore obvious that aluminium in a fire hazard area must be protected.

It is no doubt that aluminium can replace steel in parts of an offshore construction, but some criteria must be maintained:

* The insulated aluminium construction must have the provided fire resistance. (Both stability, integrity and insulation).

* To defend the use of aluminium at all, the insulated aluminiumconstruction should not be heavier than the steel construction with equal capasity. In addition to this, characteristics related to corrosion and costs must be considered.

These criteria should be able to fullfill for both decks and bulkheads. However, in areas with heavy traffic, it must be considered if bumping of trucks etc. into the walls can damage the insulation on the bulkhead. It is more doubtful that aluminium can replace steel in bridges and flare towers. The thickness of the present insulation materials would be too thick and unpractical compared to the insulation on steel.

Stairways, ladders etc. should not be made of aluminium. In a situation of evacuation the main construction in the emergency exits should be intact.

Due to the few reports available on fire tested aluminium constructions it is difficult to give suggestions about design. The mentioned reports and the listed classified constructions show that it is possible to construct both A-decks and A-bulkheads in aluminium. It seems that the most reasonable way of insulating a deckconstruction is to put the insulation into a suspended ceiling. The main aspect here is to prevent the insulation from falling down during a fire. Aluminium bulkheads must be insulated on both sides. The most used insulation materials are different boards and mineral wool.

For both these constructions different types of ceramic fibres seem to be an interesting insulation material. Both weight and thermal conductivity are favourable. The material ought to be tested. If these light materials show good results, it should also be considered to test different insulated columns and beams of aluminium. For these constructions real weight savings can be achieved.

REFERENCES

(1) NS 3478

(2) Development in Fire Protection of Offshore Platforms - 1 Chapter 9. "Structural Protection and Fire Protection Claddings". A.C. Blake. Applied Science Publishers.

(3) IMO Res. A 163

(4) SOLAS Convention 1974

(5) Norwegian Petroleum Directorate: "Regulations for Production- and Auxiliary Systems on Production Installations etc."

(6) Esben J. Thrane, Jon M. Huslid: "Structrues in steel and luminium", Tapir 1979, in Norwegian.

(7) "Aluminium in Offshore Constructions", Report from Multiconsult A/S, 1975.

(8) Tests performed at The Norwegian Fire Research Laboratory.

(9) "List of equipment approved by the Norwegian Maritime Directorate", 1981.

(10) "Type approved products. Fire restricting materials and fire technical equipment". Det norske Veritas, 1982.

(11) "Passive fire protection for aluminium structures." Allen Winer & Frank Butler. Naval Engineers Journal, Dec. 1975.

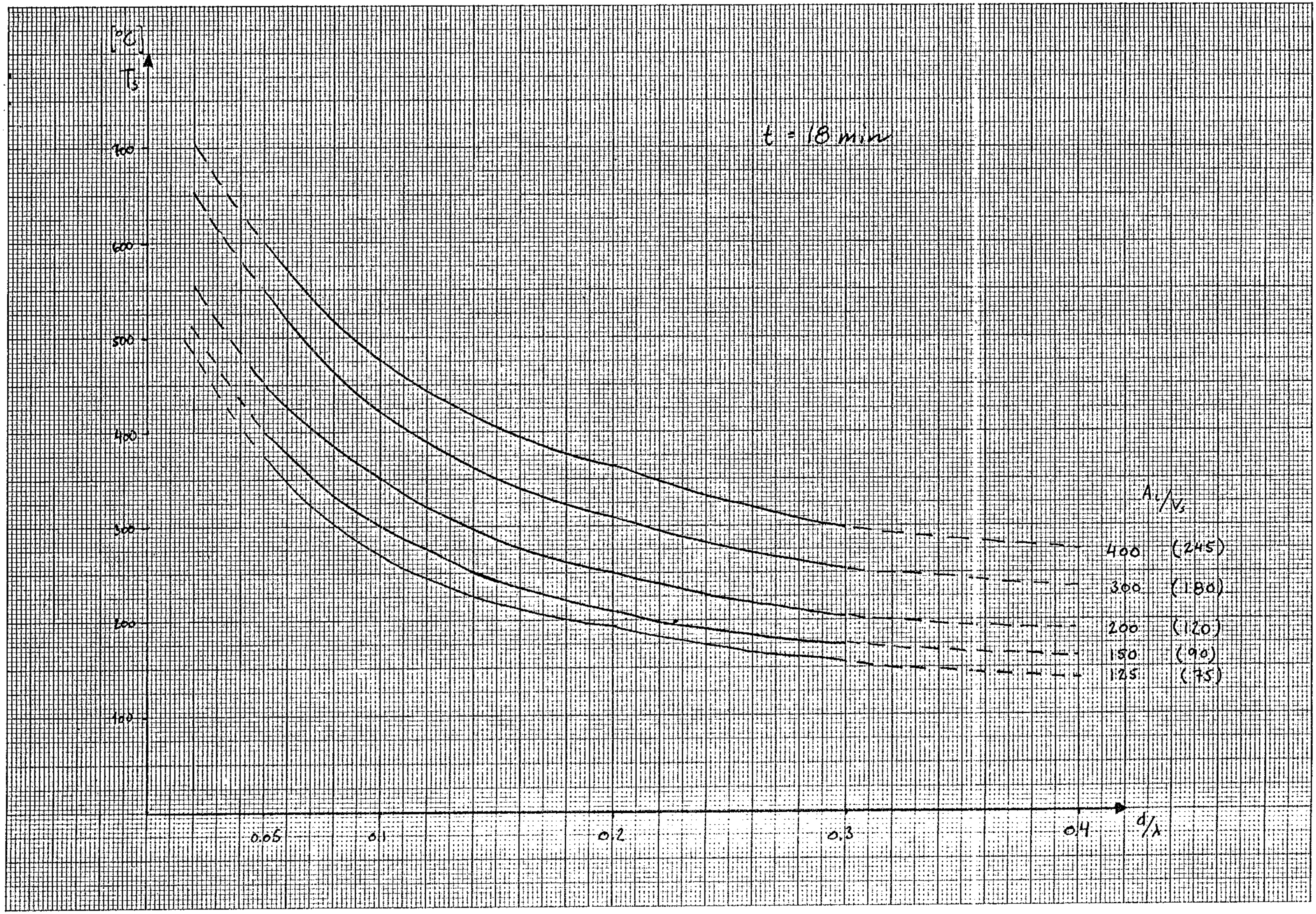
(12) "The fire risk in aluminium alloy ship's structures", Dr. E.G. West. The Metallurgist and Materials Technologist. Sept. 1982.

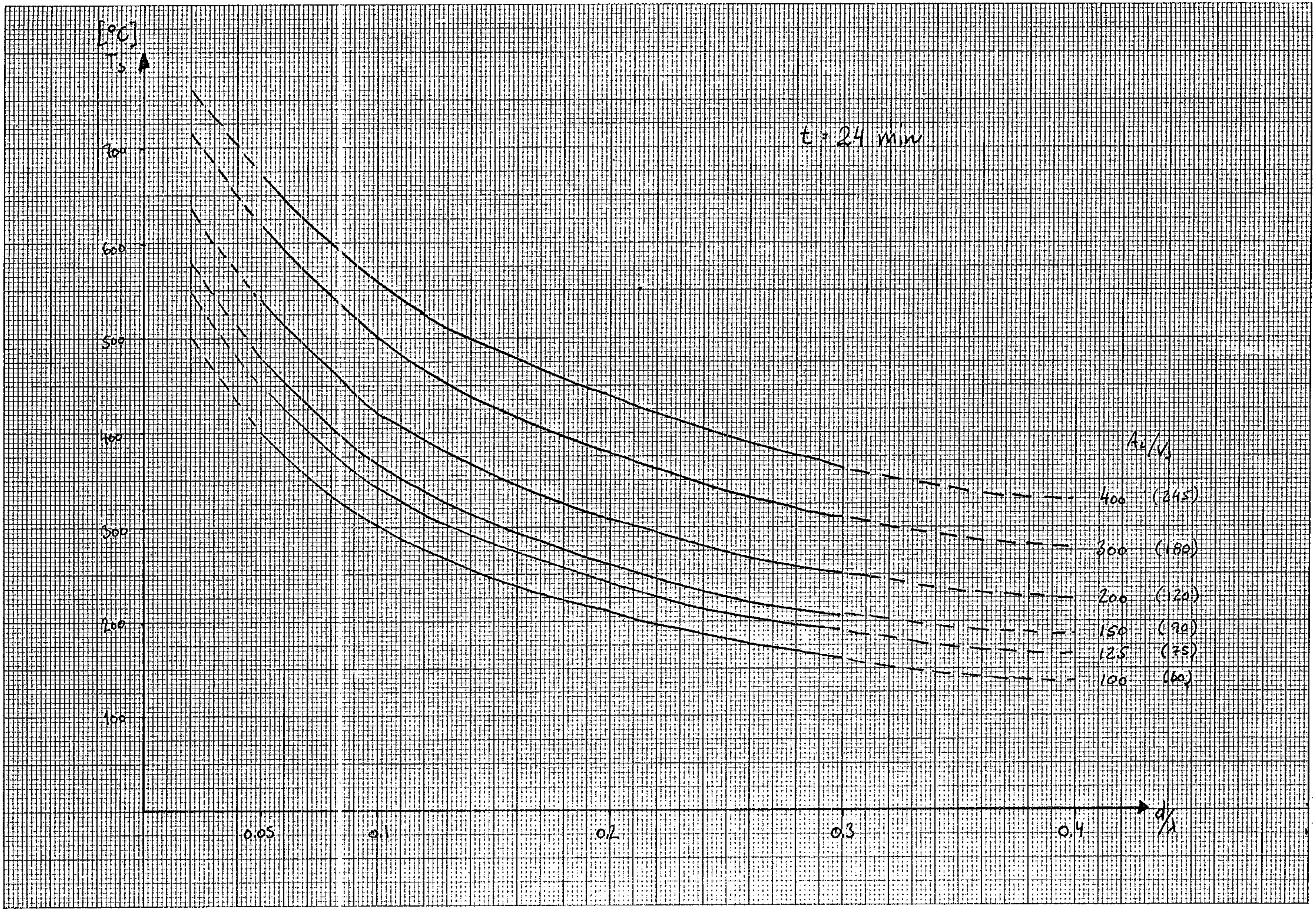
(13) "Aluminium tak - dåligt skydd och farligt för brandpersonal". Vice brandchef Birger Lennmalm. Brandförsvar 3/80, In Swedish.

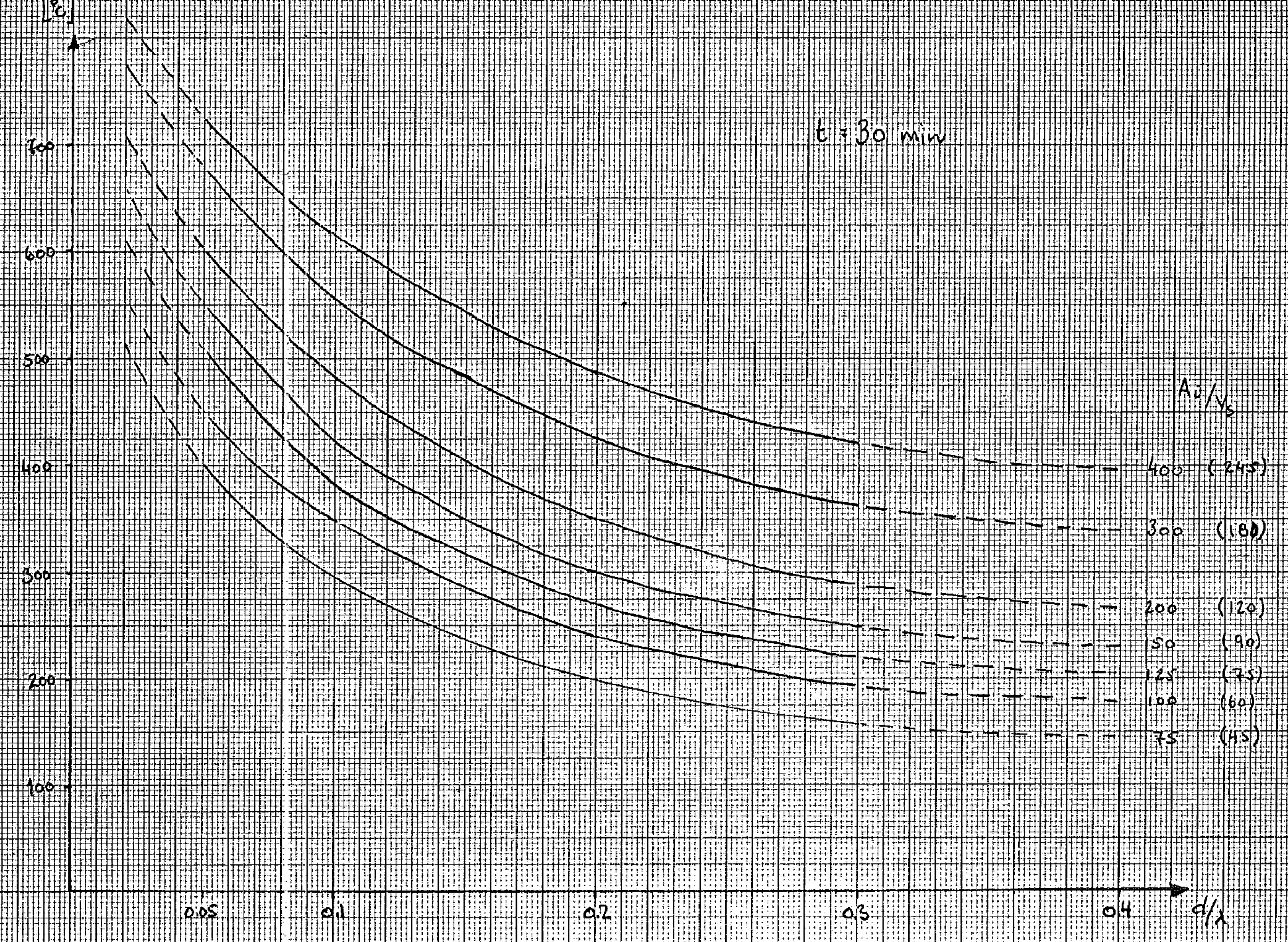
(14) Centre International de Developpement de l'Aluminium: Working panel "Fire Resistance of Aluminium Constructions" W.D. 7132.

(15) "Report on the use and performance of aluminium in naval vessels". Revised draft Sept. 1. 1982.

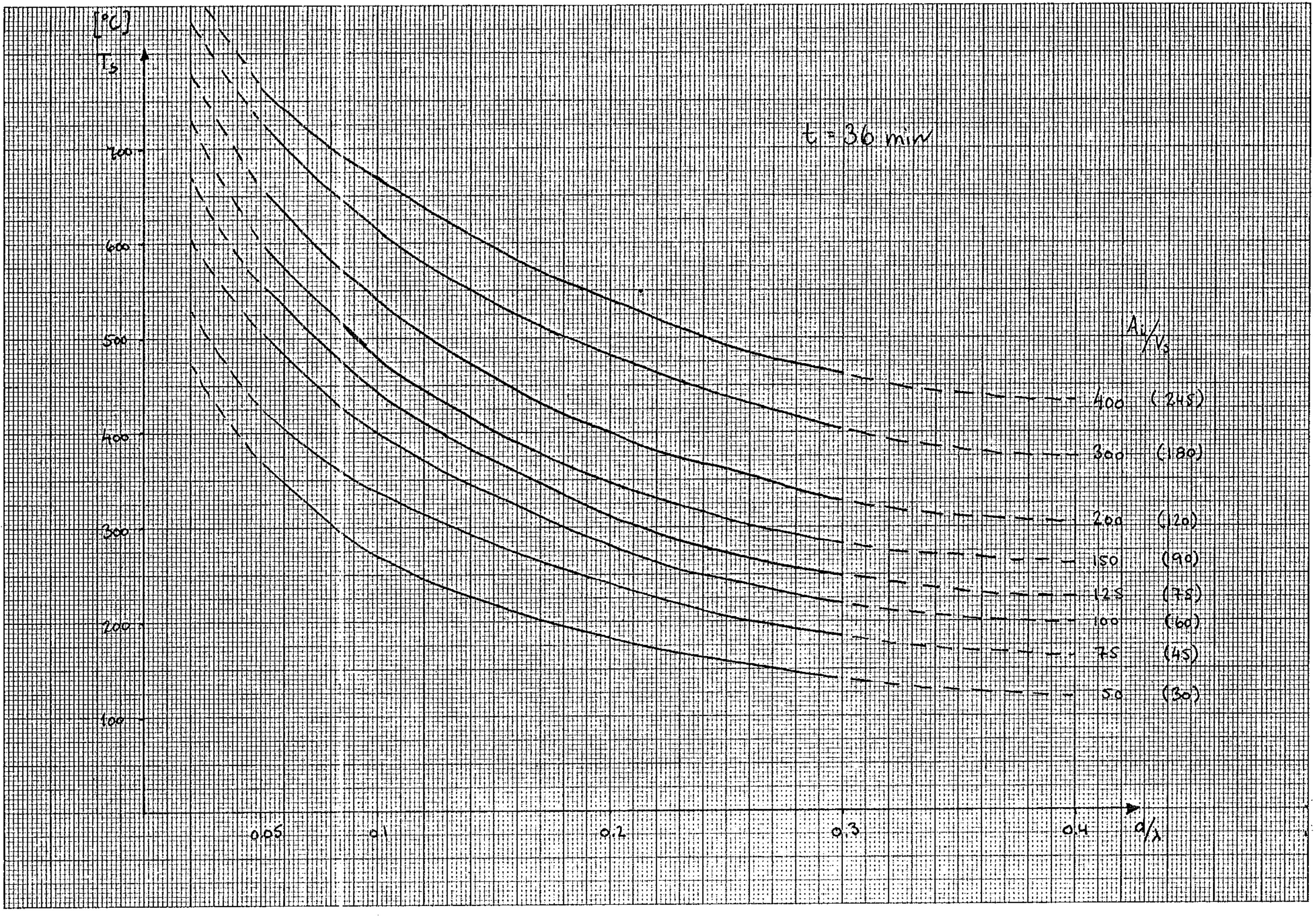
(16) NIF-kurs nov. 1980. "Brannteknisk dimensjonering av bygningskonstruksjoner. Praktiske anvendelser av NS 3478".


[°C]
T_s
t = 18 min
700
600
500
400
300
200
100
0.05
0.1
0.2
0.3
0.4
d/λ
A_i/V_s
400 (245)
300 (180)
200 (120)
150 (90)
125 (75)


[°C]
Ts
t = 24 min
700
600
500
400
300
200
100
0.05
0.1
0.2
0.3
0.4
d/λ
Ai/Vi
400 (245)
300 (180)
200 (120)
150 (90)
125 (75)
100 (60)



[°C]
t = 30 min
700
600
500
400
300
200
100
0.05
0.1
0.2
0.3
0.4
d/λ
Ai/Vs
400 (245)
300 (180)
200 (120)
150 (90)
125 (75)
100 (60)
75 (45)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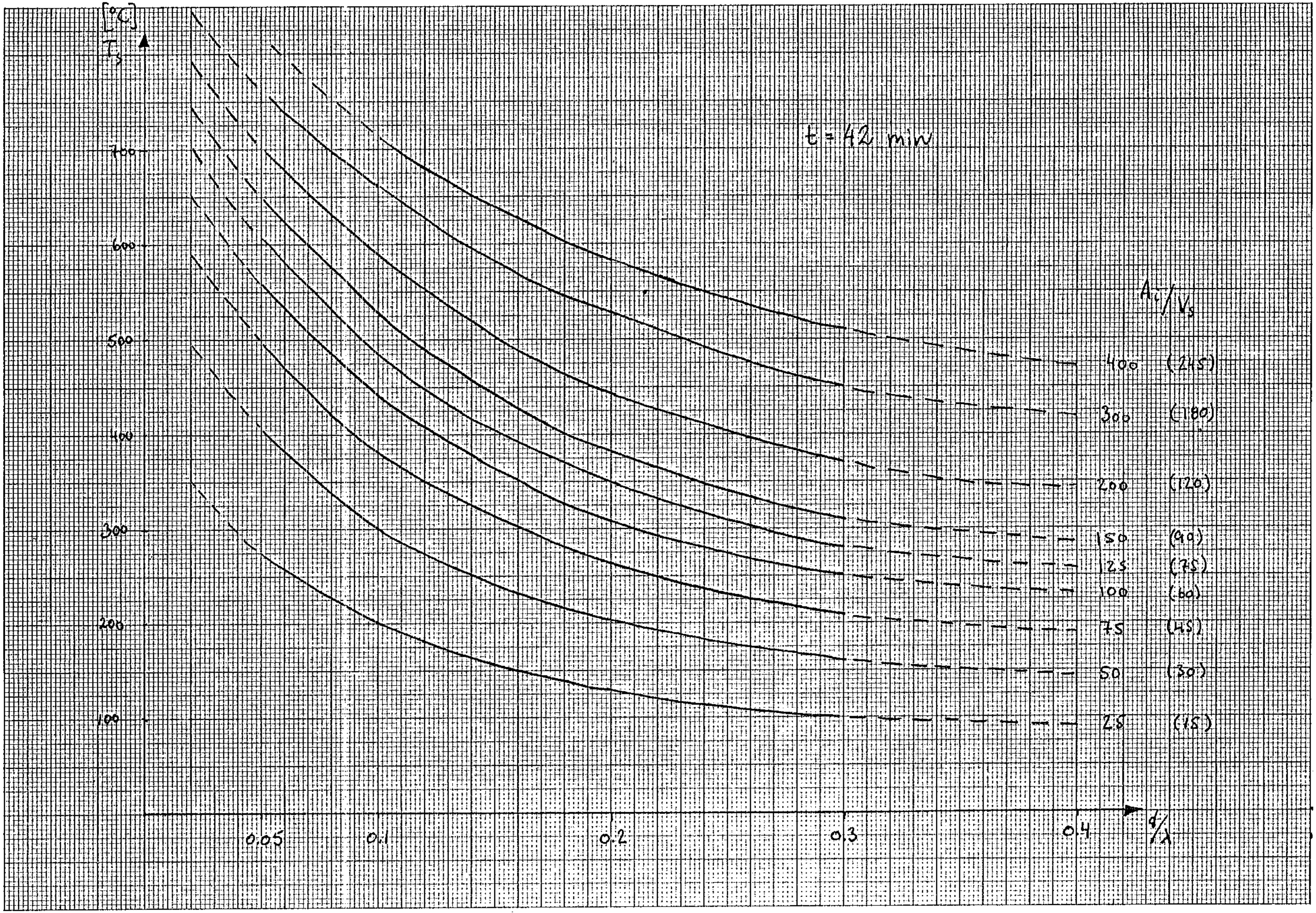
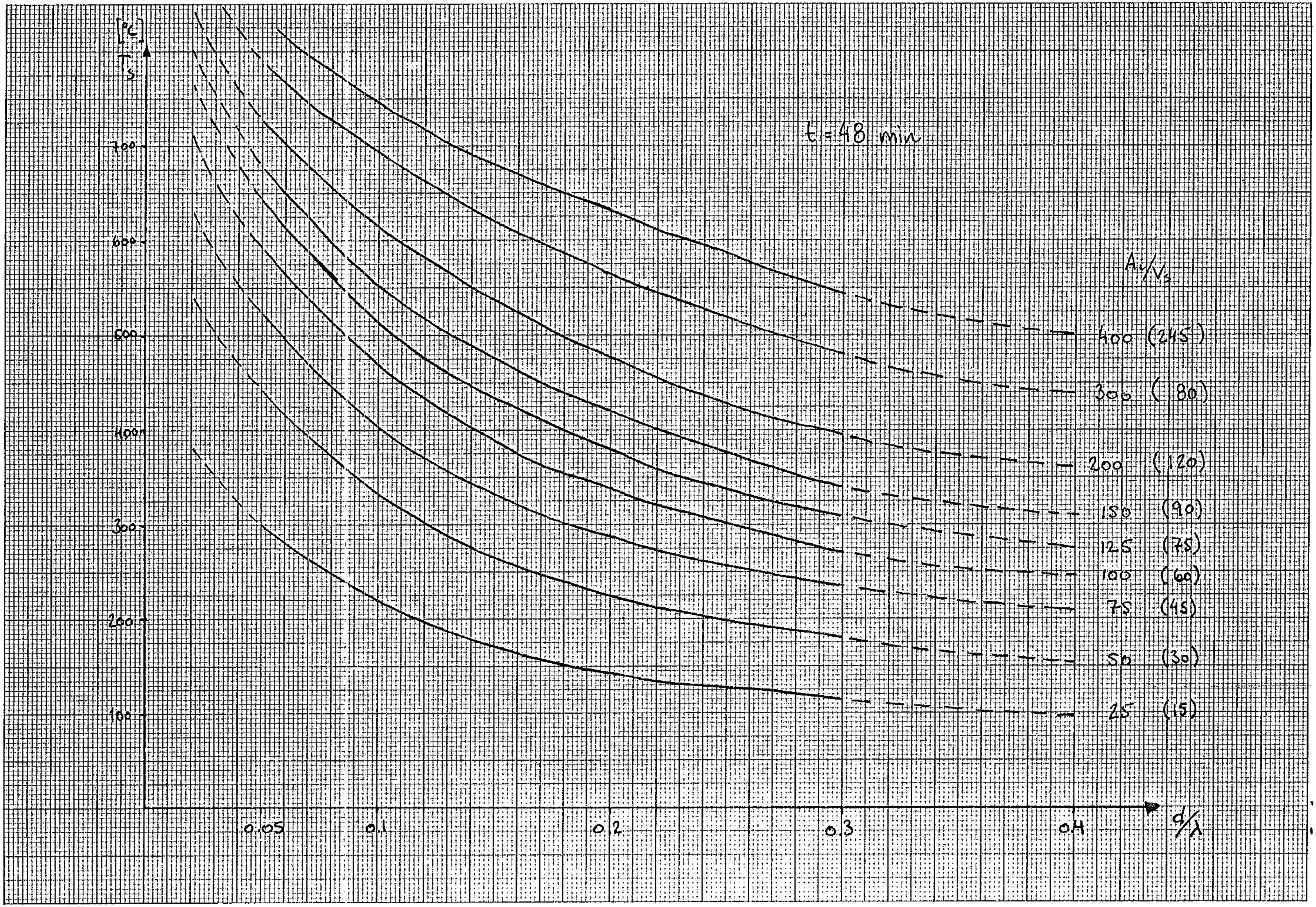
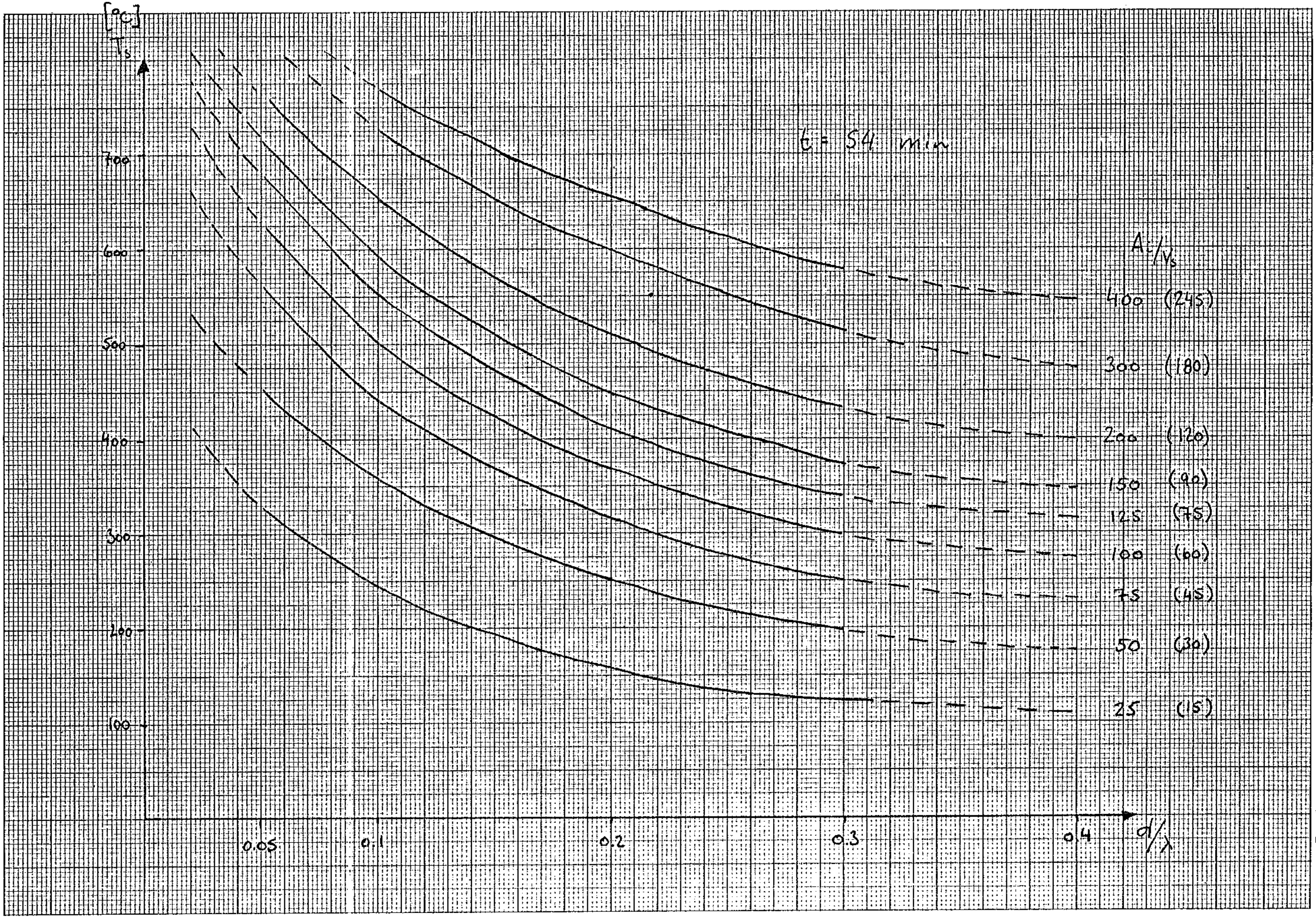
T_s
t = 36 min
700
600
500
400
300
200
100
0.05
0.1
0.2
0.3
0.4
d/λ
A_i/V_s
400 (245)
300 (180)
200 (120)
150 (90)
125 (75)
100 (60)
75 (45)
50 (30)

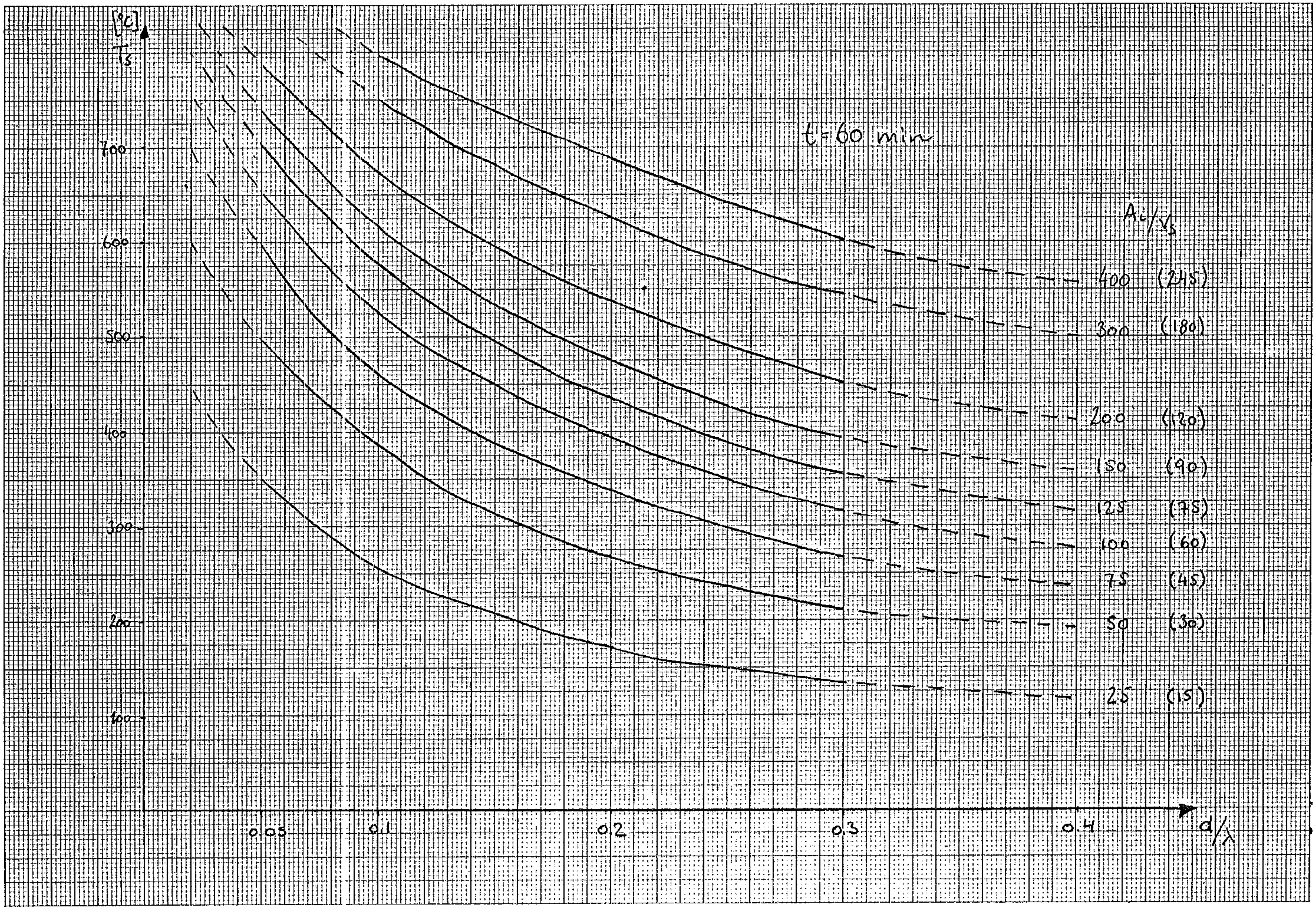


[°C]
T_s
t = 42 min
A_i/V_s
400 (245)
300 (180)
200 (120)
150 (90)
125 (75)
100 (60)
75 (45)
50 (30)
25 (15)
700
600
500
400
300
200
100
0.05
0.1
0.2
0.3
0.4
d/λ


t = 48 min
Ai/Vs
400 (245)
300 (80)
200 (120)
150 (90)
125 (75)
100 (60)
75 (45)
50 (30)
25 (15)
[°C]
Ts
700
600
500
400
300
200
100
0.05
0.1
0.2
0.3
0.4
d/λ



[°C]
T_s
t = 54 min
A_i/V_s
400 (245)
300 (180)
200 (120)
150 (90)
125 (75)
100 (60)
75 (45)
50 (30)
25 (15)
700
600
500
400
300
200
100
0.05
0.1
0.2
0.3
0.4
d/λ


[°C]
Ts
700
600
500
400
300
200
100
t=60 min
Ai/Vs
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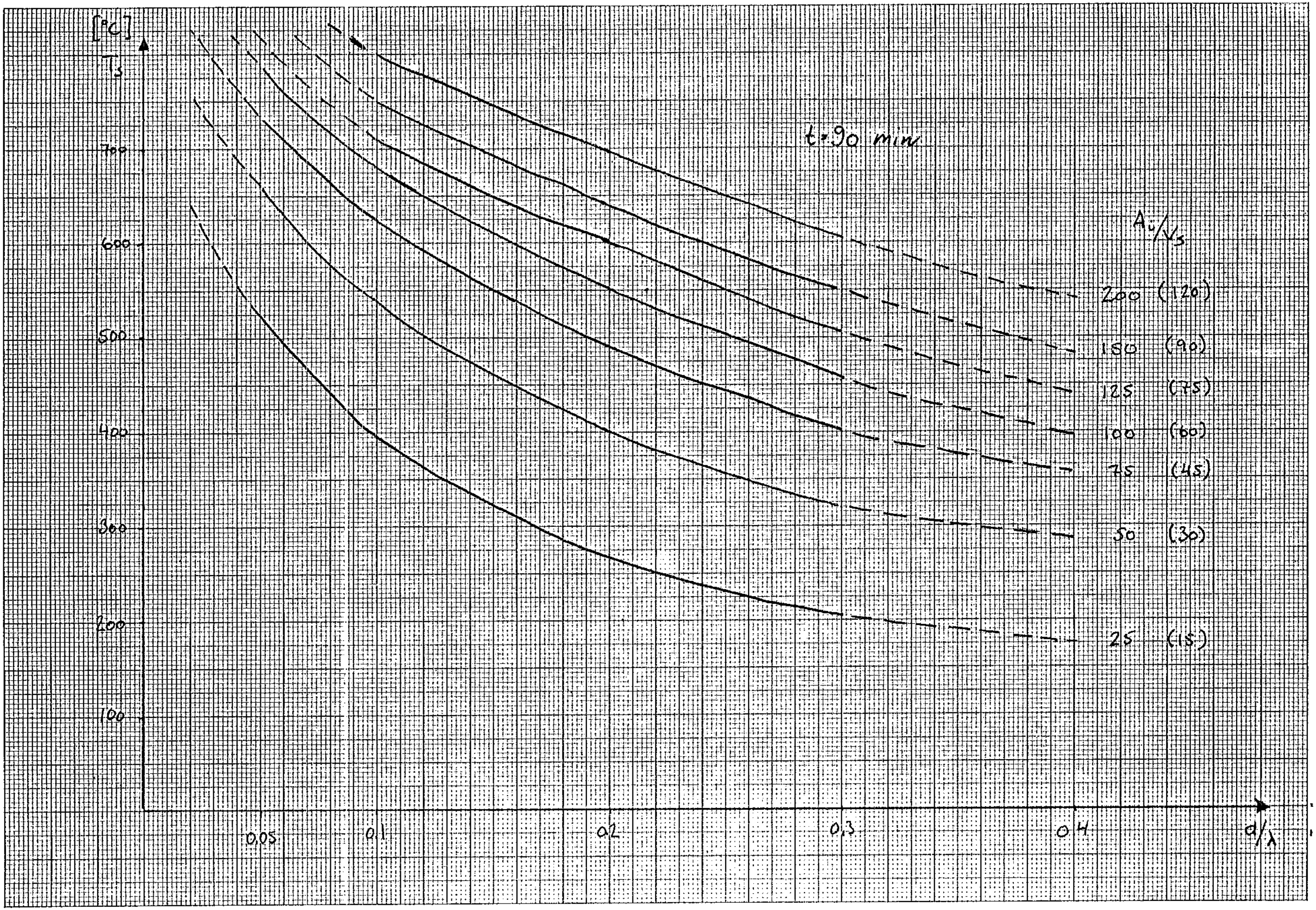
300 (180)
200 (120)
150 (90)
125 (75)
100 (60)
75 (45)
50 (30)
25 (15)
0.05
0.1
0.2
0.3
0.4
d/λ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T_s
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600
500
400
300
200
100
t=90 min
A_i/V_s
200 (120)
150 (90)
125 (75)
100 (60)
75 (45)
50 (30)
25 (15)
0,05
0,1
0,2
0,3
0,4
d/λ

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