TALAT Lectures 2503

Calculation Methods for Fire Design

31 pages, 28 figures

Basic Level

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Objectives:

- to learn how to calculate the fire resistance of aluminium alloy structures with and without applied insulation

Prerequisites:

- general engineering background
- TALAT lectures 2501 and 2502

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2503 Calculation Methods for Fire Design

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2503.01 Tests and Calculation Methods

2503.01.01 Introduction

To document the fire resistance of an aluminium alloy structure, fire resistance tests can always be used. Walls, floors, beams and columns can be tested in the fire test furnaces. Load bearing structures can be tested with their actual load.

Temperatures will always be measured on the unexposed side of a tested partition. For other building elements (beams, columns) usually temperatures are measured inside and on the outside surface of the structure.

When testing an aluminium alloy structure, the temperature of the structural part is the most interesting. The metal temperature measured can be used to determine the strength available at that temperature. The structure can then be calculated with this reduced strength. This constitutes an alternative way to practical fire testing under loads.

The good heat conduction ability of aluminium may be a problem when testing aluminium alloy structures. Small test specimen may experience a significant amount of heat transfer from the edges, and the temperature may be considerably higher than in larger test sections. If the test laboratory has little experience with testing aluminium structures, one should take care of minimizing the edge effects already when planning the test.

2503.01.02 Calculation Methods

There are several computer programmes which can be used for temperature analysis of structures exposed to fire. No particular programmes are available for calculations of aluminium alloy structures.

When calculating aluminium alloy structures at high temperatures (150 - 250 °C) time dependent creep effects will influence the behaviour of the material. One characteristic feature of creep behaviour is that, at constant stress and temperature, strain develops as shown by the creep curve in **Figure 2503.01.01**. Strain ε_0 at t = 0 denotes the stress dependent initial strain, elastic or elastic-plastic. The strain curve is generally subdivided into three creep regimes: primary, secondary and tertiary. Creep rupture occurs at the end of tertiary creep.

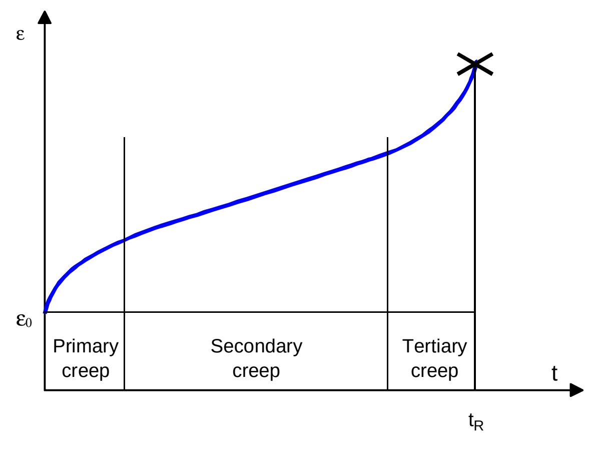
Tests have shown that the time dependent creep is neglectable for temperatures below 180 - 200 °C. ENV 1999-1-2 [15] disregard time dependent creep for temperatures below 170 °C.

Creep properties of aluminium alloys are not taken into account by any computer programme.

To design aluminium alloy structures exposed to fire, the first step will be to calculate the metal temperature of the structure. Then we can determine the reduced strength of the aluminium alloy. This value of reduced strength is used to check if the structure meets the required fire resistance according to the national codes or standards.

ENV 1999-1-2 [15] is today the only standard which deal with fire design of aluminium structures. The knowledge about the behaviour of aluminium structures at elevated temperatures is, however, limited for both insulated and uninsulated structures. ENV 1999-1-2 has rules for simple calculation of the capacity of structures at elevated temperatures. The rules for the temperature analysis are more complicated, and need the properties of the insulation materials which match the rules. Today these properties are only available for steel structures, but it is likely to believe that the same properties may be used also for aluminium structures.

For calculating the temperature of structures exposed to fire computer programmes are available. By introducing the thermal properties of aluminium alloys in these programmes, they can be used to calculate the temperature of both insulated and uninsulated aluminium alloy structures exposed to fire.



Time Dependent Creep

2503.01.01

It is the transient two-dimensional heat transfer equation which has to be solved by the finite element method [3].

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial e}{\partial t}+Q=0$$

wherex, y = coordinates (m)
T = temperature (°K)
k = thermal conductivity (W/m°K)
e = specific volumetric enthalpy (J/m^3)
t = time (s)
Q = internally generated heat (W/m^3)

The specific volumetric enthalpy (J/m³) is defined as:

$$e = \int_{T_0}^{T} c \, \rho \, dT + \sum l_i$$

where T_0 = reference temperature, usually zero °K
C = specific heat capacity (J/kg°K)
ρ = density (kg/m³)
l_i = latent heat at various temperature levels for instance due to evaporation of water or chemical reactions (J/m³)

Heat flux to boundaries may be specified as:

$$q = \varepsilon \cdot \sigma \left(T_g^4 - T_s^4 \right) + \beta \left(T_g - T_s \right)^{\gamma}$$

where ε = resultant emissivity
σ = the Stefan-Boltzmann constant (W/m²K^4)
T_g = absolute surrounding gas temperature (e.g fire temperature) (K)
T_s = absolute surface temperature (K)
ß = convective heat transfer coefficient (W/m²K)
γ = convective heat transfer power

The values for thermal conductivity and specific heat capacity, must be adapted according to the higher temperatures at the different nodes.

The computer programmes are built up around the above mentioned equations. One-dimensional calculation can be done by handcalculation but this seems rather time-consuming.

2503.02 Fire Design according to ENV 1999 - 1 - 2

The European prestandard deals with design of aluminium structures for the accidental situation of fire exposure. The prestandard must be used together with the general rules of the prestandard, ENV 1999 - 1 - 1 |17|.

The contents of the prestandard is a general part with general information and basic principles and rules, a part with material properties and a part with structural fire design containing mechanical response and temperature analysis.

The part containing material properties fits in with the material properties in this course (**Section 2502.01**).

The structural fire design part consists of simple calculation models for the resistance of the different types of members in a member analysis and a temperature analysis part for unprotected and protected aluminium structures together with aluminium structures in a void protected by heat screens and external aluminium structures.

2503.02.01 Resistance of aluminium structures at elevated temperatures

In this section the symbols for design resistance becomes M_{Rd}, N_{Rd}, V_{Rd} depending on whether the effect of actions concerned is bending moment, axial force or shear force respectively.

In a fire design situation, the classification of cross-sections can be classified as for normal temperature design according to 5.4 in ENV 1999-1-1 |17|, without any changes.

2503.02.02 Tension members

The design resistance $N_{fi,t,Rd}$ of a tension member with a non uniform temperature distribution over the cross section at time t may be determined from

$$N_{fi,t,Rd} = \sum A_i k_{0,2,\theta,i} \, f_{0,2}/\gamma_{M,fi}$$

where

A_i is an elemental area of the net cross-section with a temperature θ_i , including a deduction when required to allow for the effect of HAZ softening. The deduction is based on the reduced thickness of $k_{HAZ} \cdot t$;

$k_{0,2,\theta,i}$ is the reduction factor for the effective 0.2% proof stress at temperature θ_i. θ_i is the temperature in the elemental area A_i.

The design resistance $N_{fi,\theta,Rd}$ of a tension member with a uniform temperature θ_{al} should be determined from

$$N_{fi,\theta,Rd} = k_{0,2,\theta} \, N_{Rd} \, (\gamma_{M1}/\gamma_{M,fi})$$

where:

$k_{0,2,\theta}$ is the 0,2% proof stress ratio for the aluminium alloys strength at temperature θ_{al};

and N_{Rd} is the design resistance of the net section for normal temperature design according to ENV 1999-1-1.

It may be assumed that a tension member satisfies the requirements if at time t the aluminium temperature θ_{al} at all cross-sections is not more than 170 °C.

2503.02.03 Beams

The design moment resistance $M_{fi,t,Rd}$ of a cross-section in class 1 or 2 with a non uniform temperature distribution at time t may be determined from:

$$M_{fi,t,Rd} = \sum A_i \, z_i \, k_{0.2,\theta,i} \, f_{0.2}/\gamma_{M,fi}$$

where:

A_i is an elemental area of the net cross-section with a temperature θ_i , including a deduction when required to allow for the effect of HAZ softening. The deduction is based on the reduced thickness of $k_{HAZ} \cdot t$, according to ENV 1999-1-1;

z_i is the distance from the plastic neutral axis to the centroid of the elemental area A_i ;

$k_{0,2,\theta,i} \, f_{0,2}$ is the strength of the elemental area A_i at temperature θ_{al}.

The plastic neutral axis of cross-section with a non uniform temperature distribution is that axis perpendicular to the plane of bending which satisfies the following criterion:

$$\sum A_i \, k_{0,2,\theta,i} \, f_{0,2,i} = 0$$

The design moment resistance $M_{fi,t,Rd}$ of a cross-section in class 3 with a non-uniform temperature distribution at time t may be determined from:

$$M_{fi,t,Rd} = M_{fi,\theta,Rd}$$

where

$M_{fi,\theta,Rd}$ is the design moment resistance of the cross section for a uniform temperature θ_{al} equal to the maximum temperature $\theta_{al,max}$ reached at time t.

The design $M_{fi,t,Rd}$ of a cross-section in class 4 with a non-uniform temperature distribution at time t may be determined from:

$$M_{fi,t,Rd} = k_{0,2,\theta max} \, M_{Rd} \, (\gamma_{M1}/\gamma_{M,fi})$$

where:

$k_{0,2,\theta max}$ is the 0,2% proof stress ratio for the aluminium alloys strength at temperature θ_{al} equal to the maximum temperature $\theta_{al,max}$ of the cross section reached at time t;

and M_{Rd} is the moment resistance of the cross-section for normal temperature design for class 4 according to ENV 1999-1-1.

The design $M_{fi,t,Rd}$ of a cross-section in class 1, 2, 3 or 4 with a uniform temperature distribution at time t may be determined from:

$$M_{fi,t,Rd} = k_{0,2,\theta}\, M_{Rd}\, (\gamma_{M1}/\gamma_{M,fi})$$

where:

$k_{0,2,\theta}$ is the 0,2% proof stress ratio for the aluminium alloys strength at temperature θ_{al}
M_{Rd} is the moment resistance of the cross-section for normal temperature design.

For beams subjected to lateral-torsional buckling, the design buckling resistance moment $M_{b,fi,t,Rd}$ of a laterally unrestrained beam at time t may be determined using:

$$M_{b,fi,t,Rd} = k_{0,2,\theta,max}\, M_{b,Rd}\, (\gamma_{M1}/\gamma_{M,fi})$$

where:

$k_{0,2,\theta,max}$ is the 0,2% proof stress ratio of aluminium alloy at temperature θ_{al} equal to the maximum aluminium alloy temperature $\theta_{al,max}$.
$M_{b,Rd}$ is the design buckling resistance moment for normal temperature design, according to ENV 1999-1-1.

The design shear resistance $V_{fi,t,Rd}$ of a beam at time t may be determined from:

$$V_{fi,t,Rd} = k_{0,2,\theta}\, V_{Rd}\, (\gamma_{M1}/\gamma_{M,fi})$$

where:

$k_{0,2,\theta}$ is the 0,2% proof stress ratio for the aluminium alloys strength at temperature θ_{al}. θ_{al} is the max temperature of that part of the cross section which carry the shear force.
V_{Rd} is the shear resistance of the net cross-section for normal temperature design, according to ENV 1999-1-1.

It may be assumed that a beam satisfy all the requirements if at time t the aluminium alloy temperature θ_{al} at all cross-sections is not more than 170 °C.

2503.02.04 Columns

The design buckling resistance $N_{b,fi,t,Rd}$ of a compression member at time t may be determined from:

$$N_{b,fi,t,Rd} = k_{0,2,\theta,max}\, N_{b,Rd}\, (\gamma_{M1}/1{,}2\gamma_{M,fi})$$

where:

$N_{b,Rd}$ is the buckling resistance for normal temperature design according to ENV 1999 Part 1.1.

$k_{0.2,\theta max}$ is the 0,2% proof stress ratio of aluminium alloy at temperature θ_{al} equal to the maximum aluminium alloy temperature $\theta_{al,max}$.

The constant 1,2 in this expression is a reduction factor of the design resistance due to the temperature dependent creep of aluminium alloys.

For the determination of the slenderness ratio the provisions of ENV 1999-1-1 apply.

Column lengths in non-sway frames continuously or semi-continuously connected to column lengths in other compartments, may be considered to be completely fixed in direction at such connections, provided that the resistance to fire of the building components which separate the fire compartments concerned is at least equal to the fire resistance of the column.

The design buckling resistance $R_{fi,t,d}$ of a member subjected to combined bending and axial compression at time t may be determined from:

$$R_{fi,t,d} = k_{0.2,\theta max}\, R_d$$

where:

R_d represent a combination of axial compression and bending moments $N_{fi,Ed}$, $M_{y,fi,Ed}$, and $M_{z,fi,Ed}$ such that for normal temperature design the provisions in ENV 1999-1-1 for all types of members are satisfied when:

$$N_{Sd} = 1{,}2\, N_{fi,Ed}$$
$$M_{y,Sd} = M_{y,fi,Ed}$$
$$M_{z,Sd} = M_{z,fi,Ed}$$

It may be assumed that a column satisfy these requirements if at time t the aluminium temperature θ_{al} at all cross-sections is not more than 170 °C.

2503.02.05 Connections

The resistance of connections between members need not be checked provided that the thermal resistance $(d_p / \lambda_p)_c$ of the fire protection of the connection is not less than the minimum value of the thermal resistance $(d_p / \lambda_p)_m$ of the fire protection of any of the aluminium alloy members joined by that connection.

where:

d_p is the thickness of the fire protection material

λ_p is the effective thermal conductivity of the fire protection material.

For welded connections the reduced strength in the heat affected zones must be taken into account.

2503.02.06 Temperature analysis for unprotected aluminium structures

For uninsulated aluminium structures with an equivalent uniform temperature distribution in the cross-section, the increase of temperature $\Delta\theta_{al(t)}$ during a time interval Δt should be determined from:

$$\Delta\theta_{al(t)} = \frac{1}{c_{al} \cdot \rho_{al}} \cdot \frac{A_m}{V} \cdot \dot{h}_{net,d} \cdot \Delta t$$

where:
c_{al} is the specific heat of aluminium alloys (J/kg °C)
ρ_{al} is the unit mass of aluminium (kg/m³)
A_m/V is the section factor for unprotected aluminium alloy members (m^{-1})
A_m is the exposed surface area of the member per unit length (m²/m)
V is the volume of the member per unit length (m³/m)
$\dot{h}_{net,d}$ is the design value of the net heat flux per unit area (W/m^2)
Δt is the time interval (seconds)

Calculation of $\dot{h}_{net,d}$ is described in ENV 1991 Part 2 - 2 |16|:

$$\dot{h}_{net,d} = \gamma_{n,c} \cdot \dot{h}_{net,c} + \gamma_{n,r} \cdot \dot{h}_{net,r}$$

$\gamma_{n,c} = \gamma_{n,r} = 1{,}0$ for most cases.

The previous equation will than be:

$$\dot{h}_{net,d} = \alpha_c \cdot \left(\theta_g - \theta_m\right) + \Phi \cdot \varepsilon_{res} \cdot 5{,}67 \cdot 10^{-8} \cdot \left[\left(\theta_r + 273\right)^4 + \left(\theta_m + 273\right)^4\right]$$

where:	α_c	coefficient of heat transfer by convection (W/m^2°K)
	θ_g	gas temperature of the environment of the member in fire exposure (°C)
	θ_m	surface temperature of member (°C)
	Φ	configuration factor
	ε_{res}	resultant emissivity
	θ_r	radiation temperature of the environment of the member, may be represented by the gas temperature, θ_g, (°C)

5,67 · 10^{-8} is Stefan Boltzmann constant in W/m^2°K^4.

The resultant emissivity, ε_{res}, is formulated as:

$$\varepsilon_{res} = \varepsilon_f \cdot \varepsilon_m$$

where:	ε_f	emissivity related to the fire compartment, usually taken as 0,8
	ε_m	emissivity related to surface material; the following values may be used:

ε_m = 0,3 (leading to ε_{res} = 0,24) for clean uncovered surfaces and

ε_m = 0,7 (leading to ε_{res} = 0,56) for painted and covered surfaces,

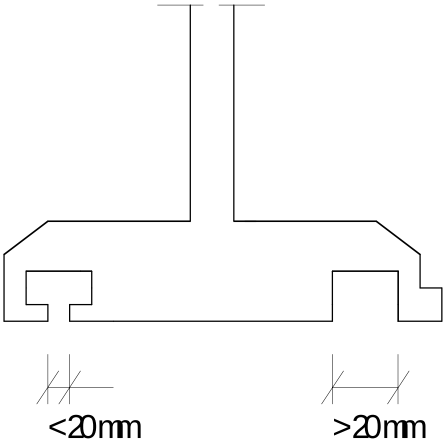
In the performance of the calculation the following must be taken into consideration:

The value of Δt should not be taken as more than 5 seconds.

The value of the shape factor A_m/V should not be taken as less than 10 m^{-1}.

When calculating the exposed surface area of the member, A_m, grooves with gap in the surface less than 20 mm should not be included in the exposed surface area (see **Figure 2503.02.01**).

Some design values of the section factor A_m/V for unprotected aluminium alloy members are given in **Figure 2503.02.02**,. **Figure 2503.02.03** and **Figure 2503.02.04.**



Grooves with gap in the surface < 20 mm, area of groove not to be included in the area of the exposed surface.
Grooves with gap in the surface > 20 mm, area of the groove to be included in the area of

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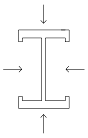
Calculation of the exposed surface in case of grooves

2503.02.01

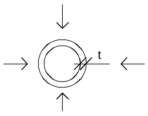
Open section exposed to fire on all sides:

$$\frac{A_m}{V} = \frac{\text{perimeter}}{\text{cross - section area}}$$



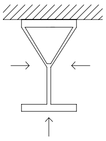
Tube exposed to fire on all sides:

$$\frac{A_m}{V} = \frac{1}{t}$$

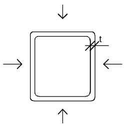


Open section exposed to fire on three sides:

$$\frac{A_m}{V} = \frac{\text{surface exposed to fire}}{\text{cross - section area}}$$



Hollow section (or welded box section of uniform thickness) exposed to fire on all sides:
If t << b: $A_m/V = 1/t$



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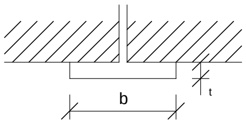
Section factor A_m/V for unprotected structural aluminium alloy members when using the lumped mass method (I)

2503.02.02

I section flange exposed to fire on three sides:

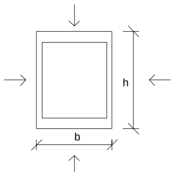
$A_m/V = (b + 2t_f)/(b\ t_f)$

If t<<b: $A_m/V = 1/tf$



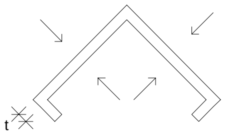
Box section exposed to fire on all sides:

$$\frac{A_m}{V} = \frac{2(b + h)}{\text{cross - section area}}$$



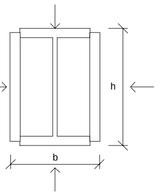
Angle (or any open section of uniform thick-ness) exposed to fire on all sides:

$A_m/V = 2/ t$



I section with box reinforcement, exposed to fire on all sides:

$$\frac{A_m}{V} = \frac{2(b + h)}{\text{cross - section area}}$$



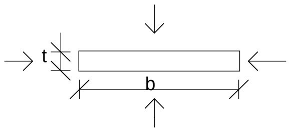
Section factor A_m/V for unprotected structural aluminium alloy members when using the lumped mass method (II)

2503.02.03

Flat bar exposed to fire on all sides:

$A_m/V = 2(b + t)/(b\ t)$

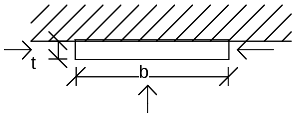
If t << b: $A_m/V = 2/ t$



Flat bar exposed to fire on three sides:

$A_m/V = (b +2\ t)/(b\ t)$

If t << b: $A_m/V = 1/ t$



Section factor A_m/V for unprotected structural aluminium alloy members when using the lumped mass method (III)

2503.02.04

2503.02.07 Temperature analysis for protected aluminium structures

For insulated aluminium structures with an uniform temperature distribution in a cross-section, the temperature increase $\Delta\theta_{al(t)}$ during a time interval Δt, should be determined from:

$$\Delta\theta_{al(t)} = \frac{\lambda_p / d_p}{c_{al} \cdot \rho_{al}} \cdot \frac{A_p}{V} \left[\frac{1}{1+\phi/3} \right] \left(\theta_t - \theta_{al} \right) \Delta t - \left(e^{\phi/10} - 1 \right) \Delta\theta_{(t)}$$

but $\Delta\theta_{al(t)} \geq 0$

in which:

$$\phi = \frac{c_p \rho_p}{c_{al} \rho_{al}} d_p \frac{A_p}{V}$$

where:

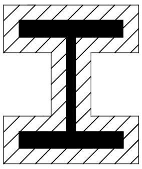
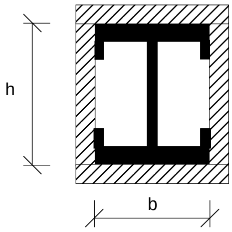
A_p/V	is the section factor for aluminium alloy members insulated by fire protection material (m^{-1})
A_p	is the area of the inner surface of the fire protection material, per unit length of the member (m^2/m)
V	is the volume of the member per unit length (m^3/m)
c_{al}	is the specific heat of aluminium alloys, (J/kg °C)
c_p	is the specific heat of the fire protection material, (J/kg °C)
d_p	is the thickness of the fire protection material (m)
Δt	is the time interval (seconds)
$\theta_{(t)}$	is the ambient gas temperature at time t (°C)
$\theta_{al(t)}$	is the aluminium temperature at time t (°C)
$\Delta\theta_{(t)}$	is the increase of the ambient temperature during the time interval Δt (°C)
λ_p	is the thermal conductivity of the fire protection material, (W/m °C)
ρ_{al}	is the unit mass of aluminium alloys (kg/m^3)
ρ_p	is the unit mass of the fire protection material, (kg/m^3)

In the performance of the calculation the following must be taken into consideration:

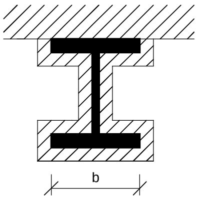
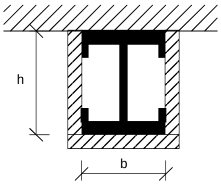
The value of Δt should not be taken as more than 30 seconds.

Some design values of the section factor A_p/V for insulated aluminium alloy members are given in **Figure 2503.02.05** and **Figure 2503.02.06**.

For moist fire protection materials the calculation of the aluminium alloy temperature increase $\Delta\theta_{al(t)}$ may be modified to allow for a time delay in the rise of the aluminium alloy temperature when it reaches 100 °C. This delay time should be determined by a method conforming with a prENV, ENV, prEN or EN.

Sketch	Description	Section factor A_p/V
	Contour encasement of uniform thickness.	$\frac{\text{aluminium perimeter}}{\text{aluminium cross - section area}}$
	Hollow encasement of uniform thickness.	$\frac{2\,(b + h)}{\text{aluminium cross - section area}}$

TALAT Training in Aluminium Application Technologies | Section factor A_p/V for structural aluminium alloy members insulated by fire protetion materials when using the lumped mass method (I) | 2503.02.05

Sketch	Description	Section factor A_p/V
	Contour encasement of uniform thickness, exposed to fire on three sides.	$\frac{\text{aluminium perimeter - b}}{\text{aluminium cross - section area}}$
	Hollow encasement of uniform thickness, exposed to fire on three sides.	$\frac{2h + b}{\text{aluminium cross - section area}}$

TALAT Training in Aluminium Application Technologies | Section factor A_p/V for structural aluminium alloy members insulated by fire protetion materials when using the lumped mass method (II) | 2503.02.06

2503.02.08 Internal aluminium structures in a void which is protected by heat screens.

The provisions given below apply to both of the following cases:

- aluminium members in a void which is bordered by a floor on top and by a horizontal heat screen below
- aluminium members in a void which is bordered by vertical heat screens onboth sides.

The properties and performance of the heat screens shall be determined using a test procedure conforming with a prENV, ENV, prEN or EN.

The temperature development in the void in which the aluminium members are situated shall be determined from a standard fire test or calculated using an approved method.

For internal aluminium structures protected by heat screens, the calculation of the aluminium temperature increase $\Delta\theta_{al}$ should be based on the methods given in this section, taking the ambient gas temperature θ_t as equal to the gas temperature in the void.

Values of the heat transfer coefficients α_c and α_r determined from tests conforming with a prENV, ENV, prEN or EN may be used in the calculation of $\Delta\theta_{al}$ as an alternative to the values given in Eurocode 1: Part 2.2.

External aluminium structures.

The temperature in external aluminium structures shall be determined taking into account:

- the radiative heat flux from the fire compartment
- the radiative heat flux and the convection heat flux from flames emanating from openings
- the radiative and convective heat loss from the aluminium structure to the ambient atmosphere
- the sizes and locations of the structural members.

Heat screens may be provided on one, two or three sides of an external aluminium alloy member in order to protect it from radiative heat transfer.

Heat screens should be either:

∗ directly attached to that side of the aluminium member which is intended to protect, or

∗ large enough to fully screen this side from the expected radiative heat flux.

Heat screens should have an integrity which corresponds to the fire resistance required for the aluminium member.

When deciding the temperature in external aluminium structures protected by heat screens, it should be assumed that there is no radiative heat transfer to those sides which are protected by heat screens.

Calculations may be based on steady state conditions resulting from a stationary heat balance using the methods given in ENV 1999 Part 1-2 Annex B.

Design using ENV 1999 Part 1-2 Annex B should be based on the model given in Eurocode 1: Part 2.2 describing the compartment fire conditions and the flames emanating from openings, on which the calculation of the radiative and convective heat fluxes should be based.

2503.03 Simplified Calculation Methods

- Uninsulated aluminium alloy structures
- Insulated aluminium alloy structures

The temperature analysis according to the ENV 1999-1-2 may be difficult due to lack of information about the insulation material and/or time consuming.

A simplified method is developed for calculating the metal temperature of aluminium alloy structures exposed to a standard fire. This method is described in this section and calculation examples are shown in **TALAT Lecture 2504**.

The graphs giving the metal temperature of the structure (**Figure 2503.03.03** and **Figure 2503.03.04**, **Figures 2503.03.09** till **Figure 2503.03.14**) are designed in such a way that they always will give a metal temperature higher than the value obtained by an exact computerized calculation. Using these simplified methods the results will always be conservative.

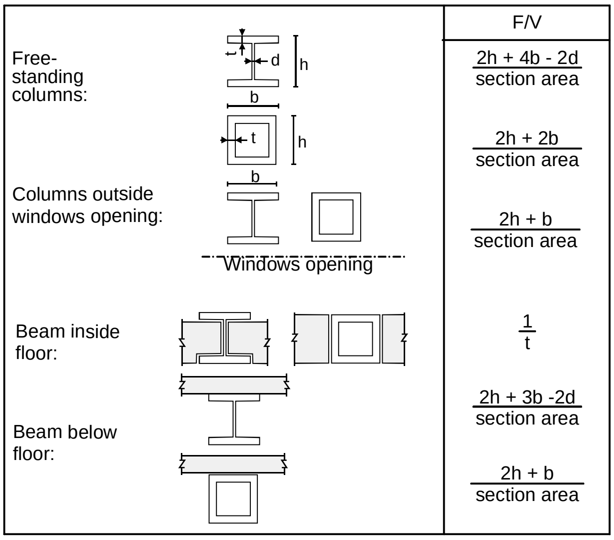
The section factor has different notations in the litterature. In this course the two most used notations are used:

$F/V = A_m/V$ = exposed surface area of member divided by the volume of the member, both per unit length.

$F_i/V = A_p/V$ = inner surface area of the insulation material divided by the volume of the member, both per unit length.

2503.03.01 Uninsulated Aluminium Alloy Structures.

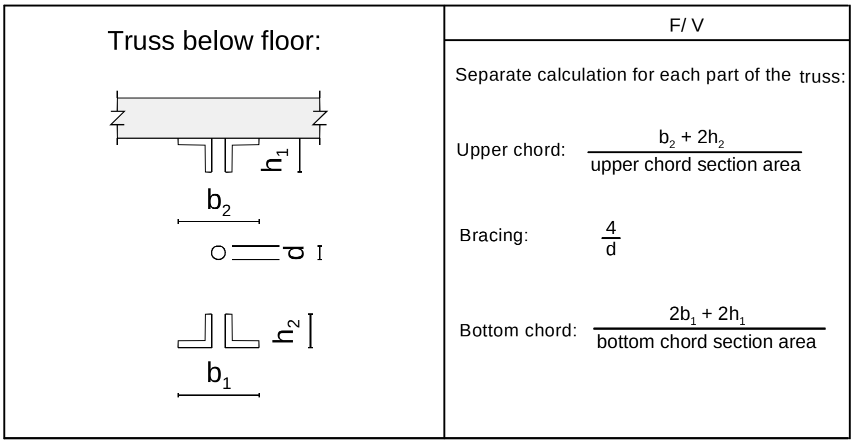
Uninsulated aluminium alloy structures exposed to the standard fire (ISO 834) may be calculated according to this method.
F/V is to be determined according to the cross section of the member and the exposed surfaces (**Figure 2503.03.01** and **Figure 2503.03.02**). It describes the ratio of the exposed surface area of the member and its volume per unit length.



F = exposed surface area of the member per unit length (m²/m)

V = volume of the exposed part of the member per unit length (m³/m)

Determination of F/ V for Columns and Beams 2503.03.01



F = exposed surface area of the member per unit length (m²/m)
V = volume of the exposed part of the member per unit length (m³/m)

Determination of F/ V for Trusses 2503.03.02

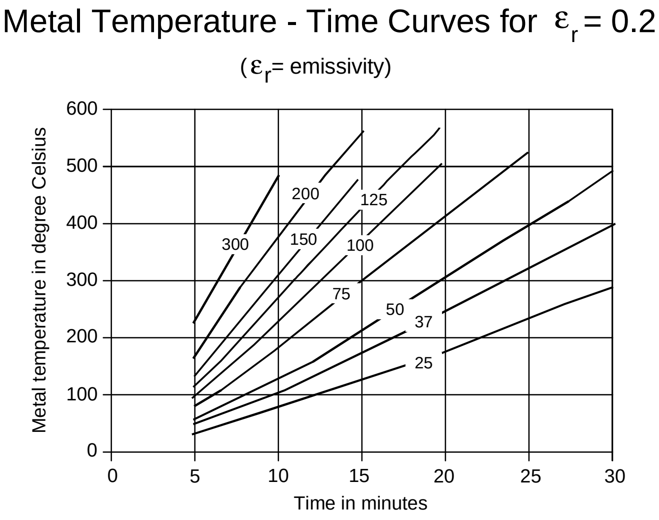
The surface of aluminium alloys has a very low emissivity. The major part of the heat radiation energy is reflected from an aluminium surface. Painted metal or a surface coated with other materials has, however, a much higher emissivity.

As a rule of thumb, the following resultant emissivities can be used:

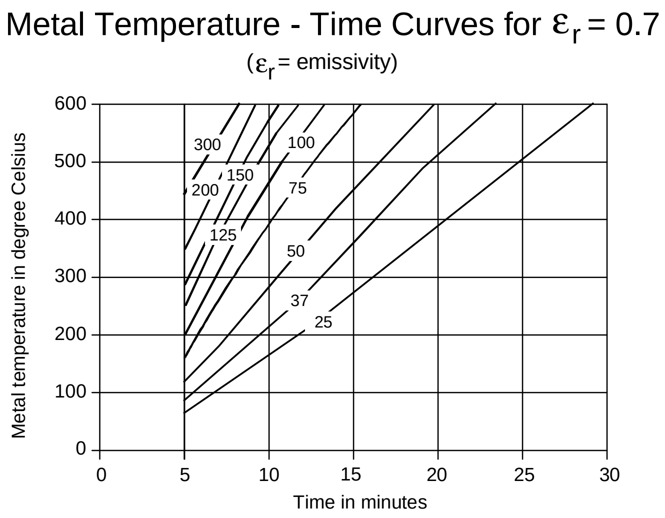
ε_r = 0,2   for external structures exposed by heat radiation through openings in partitions and for structures not getting any soot layer on the surface during the thermal exposure.

ε_r = 0,7   for all other cases.

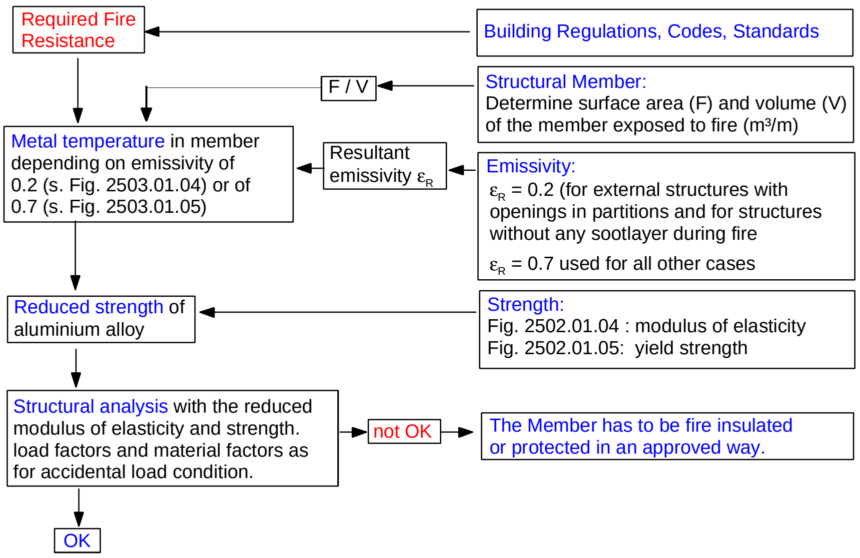
Knowing the resultant emissivity, the F/V and the exposure time for the standard fire, the metal temperature can be found using **Figure 2503.03.03** for ε_r = 0,2 and **Figure 2503.03.04** for ε_r = 0,7. When the metal temperature is known, the rules of ENV 1999-1-2 for the resistance can be used to determine the loadbearing capacity. These rules are given in **section 2503.02**.(see also **Figure 2503.03.05** for the procedure in the case of uninsulated aluminium alloy structures).



TALAT Training in Aluminium Application Technologies	Metal Temperature - Time Curves for ε_r = 0,2	2503.03.03



Metal Temperature - Time Curves for ε_r = 0,7 2503.03.04

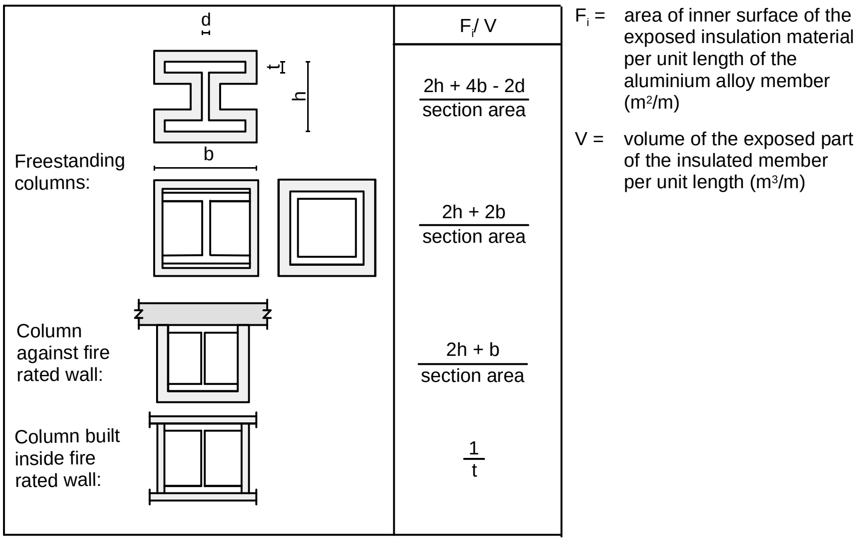


Flow Chart for Design of Uninsulated Aluminium Structures 2503.03.05

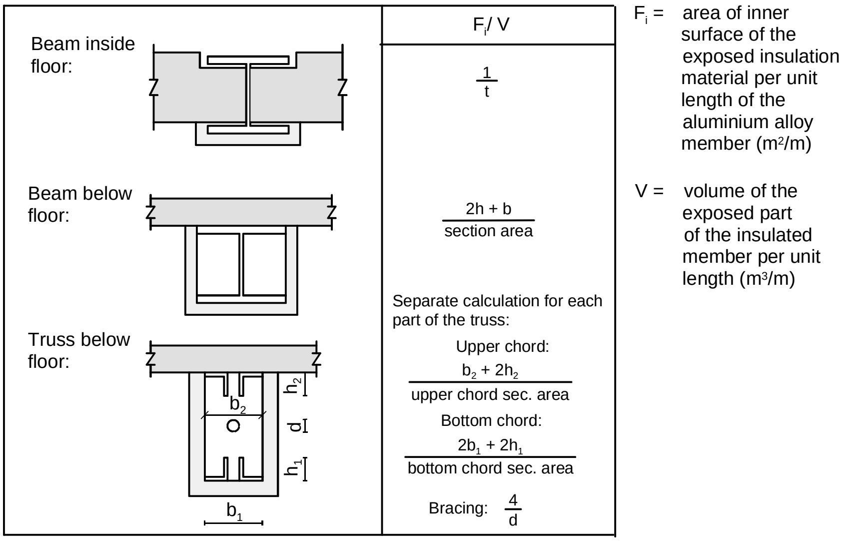
2503.03.02 Insulated Aluminium Structures

Aluminium alloy structures insulated with rockwool, ceramic fibres, calcium silicate boards, vermiculite boards or gypsum boards and exposed to a standard fire (ISO 834) may be calculated according to this method.

F_i/V is to be determined according to the section of the member, the location of the insulation and the exposed surfaces, see **Figure 2503.03.06** and **Figure 2503.03.07**.



TALAT Determination of F_i/V for Insulated Columns 2503.03.06



TALAT Determination of F_i/V for Insulated Beams and Trusses 2503.03.07

The type of insulation material and its thickness has to be chosen, the equivalent insulation thickness to be calculated by

$$t_{equ} = C \cdot t$$

where C = insulation correction factor
t = insulation thickness

The insulation correction factor to be taken from **Figure 2503.03.08**.

Insulation Material	Density kg/ m³	Ins. Corr. Factor
Rockwool Mats	30 - 40	0,45
Rockwool Mats	100 - 120	1,00
Rockwool Mats and Boards	150 - 170	1,15
Rockwool Boards	280 - 320	1,50
Ceramic Fibres Mats	120 - 150	1,30
Ceramic Fibres Boards	240 - 300	1,40
Calcium Silicate Boards	400 - 900	1/625 F_i / V +0,8
Vermiculite Boards	400 - 900	1/625 F_i / V + 0,8
Gypsium Boards	700 - 1000	1/160 F_i / V + 0,5

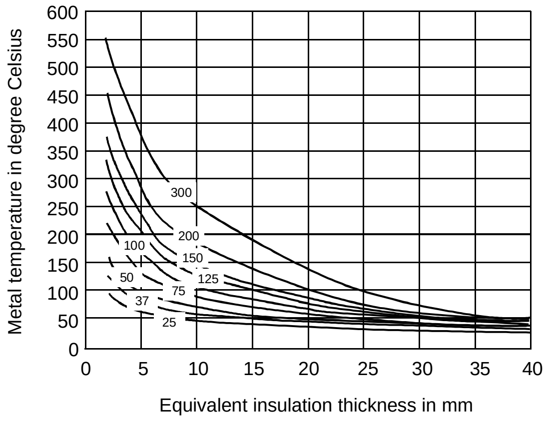
TALAT Training in Aluminium Application Technologies | Insulation Correction Factor | 2503.03.08

Knowing the equivalent insulation thickness, the F_i/V and the exposure time for the standard fire, the metal temperature of the aluminium alloy structure can be found from:

Figure 2503.03.09	for 10 min. fire resistance
Figure 2503.03.10	for 15 min. fire resistance
Figure 2503.03.11	for 30 min. fire resistance
Figure 2503.03.12	for 60 min. fire resistance
Figure 2503.03.13	for 90 min. fire resistance

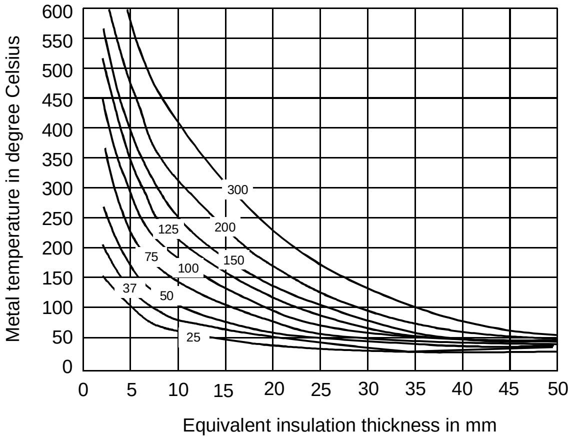
The metal temperature is used to find the modulus of elasticity and the 0,2% proof stress ratio. These values are used for checking the loadbearing capacity according to the ENV 1999-1-2.

Equivalent Insulation Thickness Versus Metal Temperature for 10 Min Fire Resistance



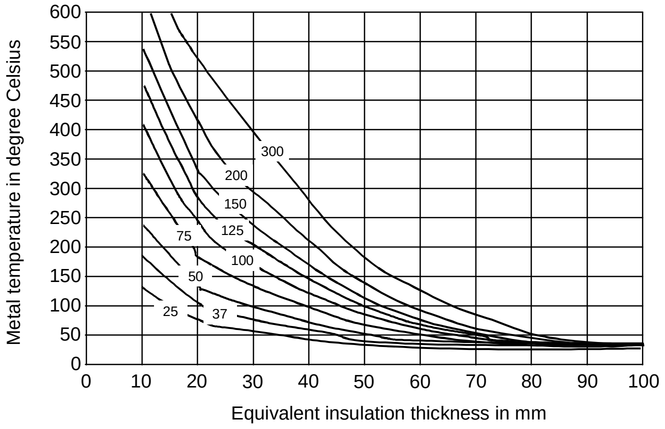
TALAT Training in Aluminium Application Technologies | Equivalent Insulation Thickness Versus Metal Temperature for 10 min Fire Resistance | 2503.03.09

Equivalent Insulation Thickness Versus Metal Temperature for 15 Min Fire Resistance

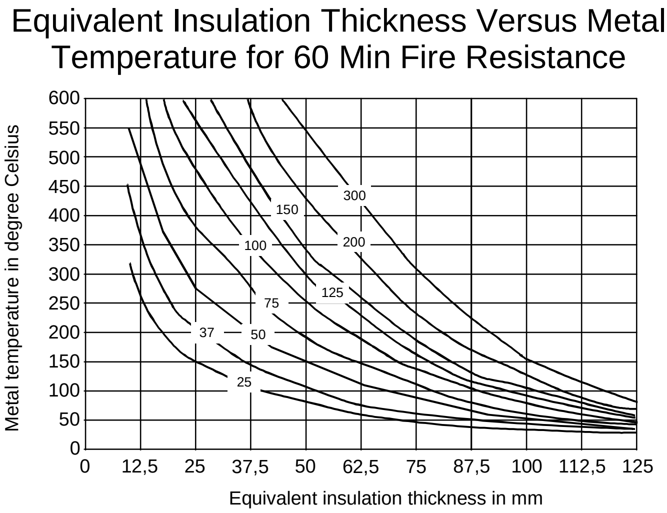


TALAT Training in Aluminium Application Technologies	Equivalent Insulation Thickness Versus Metal Temperature for 15 min Fire Resistance	2503.03.10

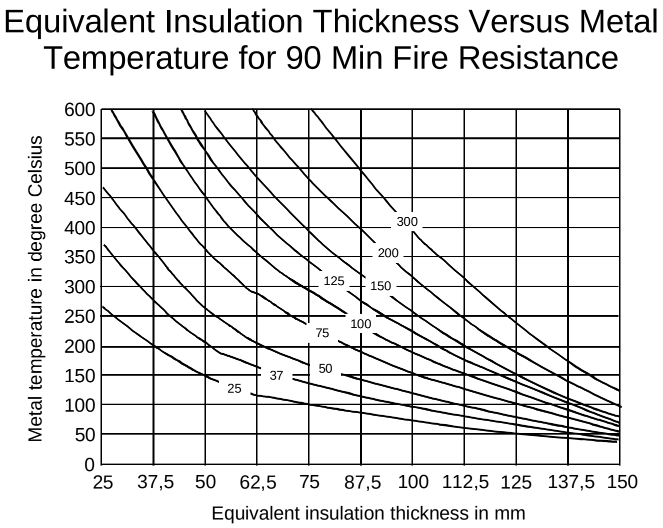
Equivalent Insulation Thickness Versus Metal Temperature for 30 Min Fire Resistance



TALAT Training in Aluminium Application Technologies	Equivalent Insulation Thickness Versus Metal Temperature for 30 Min Fire Resistance	2503.03.11



TALAT Training in Aluminium Application Technologies	Equivalent Insulation Thickness Versus Metal Temperature for 60 Min Fire Resistance	2503.03.12

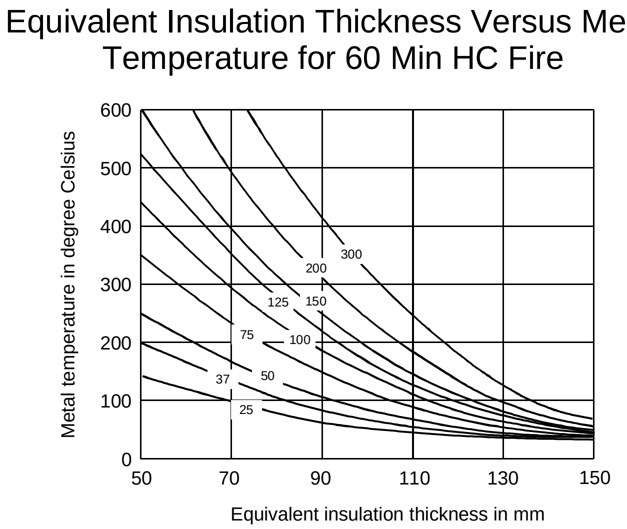


TALAT Training in Aluminium Application Technologies	Equivalent Insulation Thickness Versus Metal Temperature for 90 Min Fire Resistance	2503.03.13

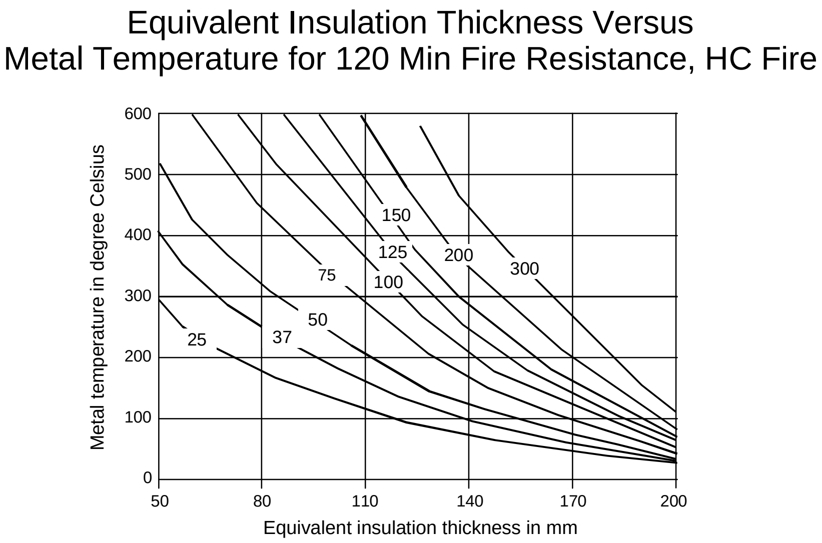
When the thermal load is a hydrocarbon fire according to the time-temperature curve described in **Figure 2501.01.05**, the same procedure can be used with the following graphs:

Figure 2503.03.14	for	60 min. fire resistance (HC-fire)
Figure 2503.03.15	for	120 min. fire resistance (HC-fire)

(The values on the curves are the F_i /V - ratios)

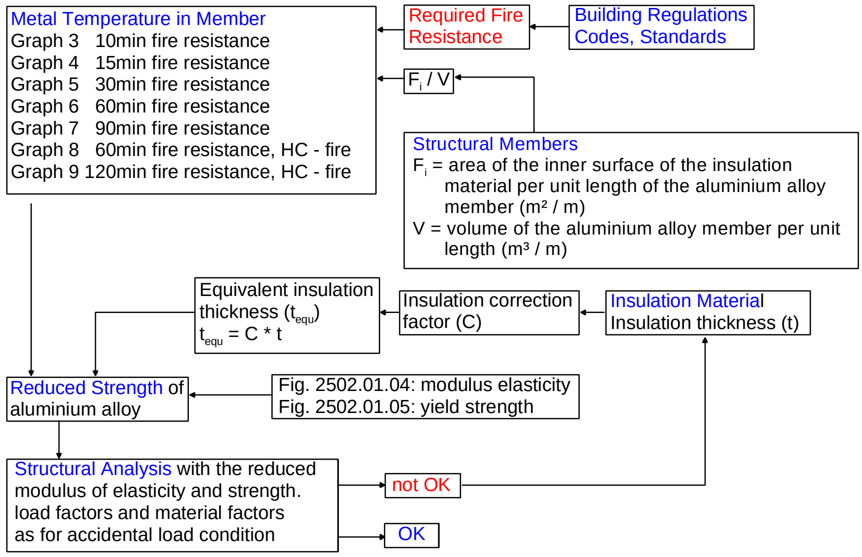


TALAT alu Training in Aluminium Application Technologies	Equivalent Insulation Thickness Versus Metal Temperature for 60 Min HC Fire	2503.03.14



TALAT alu Training in Aluminium Application Technologies	Equivalent Insulation Thickness Versus Metal Temperature for 120 Min Fire Resistance, HC Fire	2503.03.15

See also **Figure 2503.03.16** for the proceeding in the case of insulated aluminium alloy structures.



Flow Chart for Design of Insulated Aluminium Alloy Structures

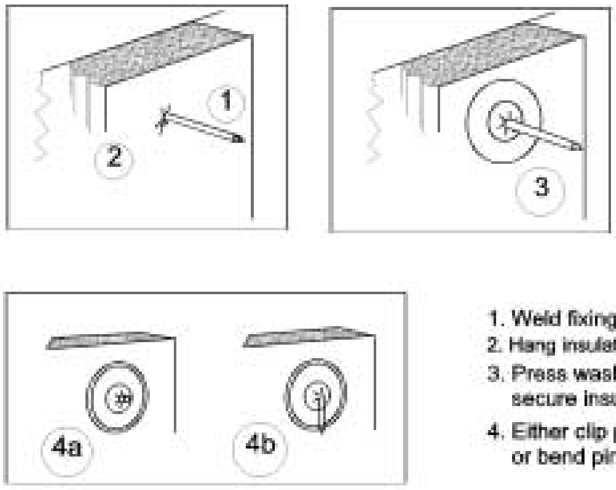
2503.03.16

2503.04 Insulation Techniques

The insulation techniques for wet insulation is different for each material. For dry insulation, however, the insulation techniques are similar.

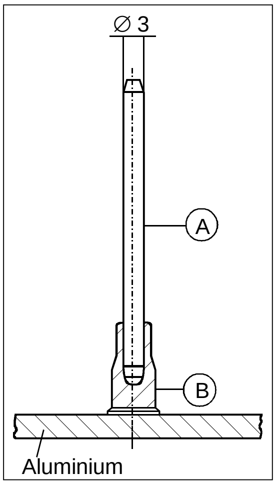
In any case, the insulation must always be installed on the exposed sides of the aluminium alloy structures, and it must be fastened in such a way that it does not fall off during exposure to fire.

For fixing dry insulation material to an aluminium alloy structure, bimetallic fixing pins can be used. These pins, consisting of stainless steel with an aluminium alloy at the fixing end can be pin-welded to the aluminium alloy structure. The insulation is to be hanged up on the pins in such a way that the pins pierce the insulation material, and the insulation is fixed by a lock washer at the end of the pins. At corners and other points where it is difficult to fasten the insulation tight, steel netting, galvanized or stainless steel, may be used (**Figure 2503.04.01** and **Figure 2503.04.02**).



1. Weld fixing pins to structure
2. Hang insulation on pins.
3. Press washer on pins to secure insulation.
4. Either clip pins of at washer (a) or bend pins over washer (b).

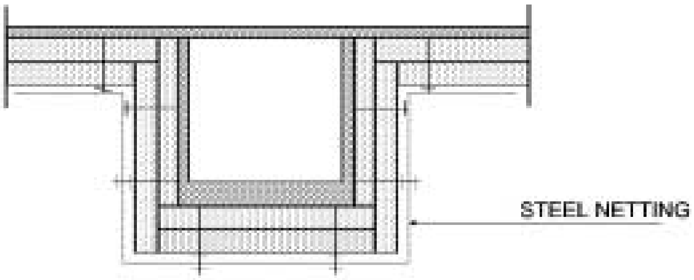
TALAT | Securing Insulation with Bimetallic Fixing Pins | 2503.04.01



Typical Bimetallic Fixing Pin

TALAT | Typical Bimetallic Fixing Pin | 2503.04.02

Many of the dry insulation materials shrink when they are exposed to fire. For this reason the insulation must be laid out in two layers with overlap at the joints (**Figure 2503.04.03**).

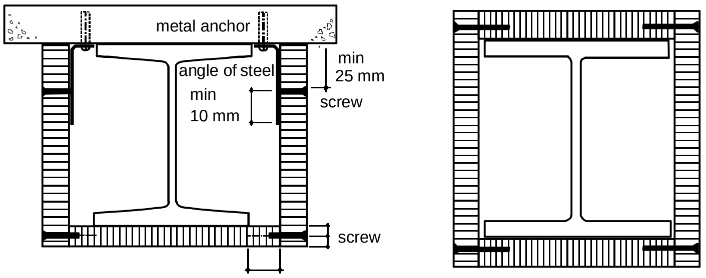


Use two overlapping layers of insulation and steel netting at the corners to avoid air gaps due to shrinkage

TALAT	Avoid Air Gaps due to Shrinkage of Insulation	2503.04.03

Examples for fixing insulation boards are given in **Figure 2503.04.04** and **Figure 2503.04.05**.

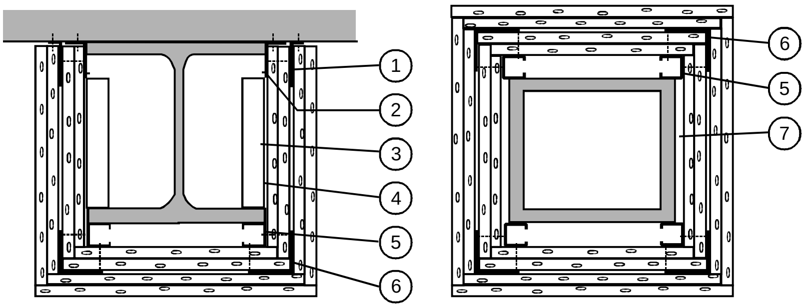
Typical Fixing Method for Stiff Insulation Boards



insulation of beam

insulation of column.

TALAT alu Training in Aluminium Application Technologies	Typical Fixing Method for Stiff Insulation Boards	2503.04.04



Typical fixing method for gypsum boards for beams (left) and columns (right)

Steel Angles : 1, 2, 3, 5, and 6
Gypsum plates : 4
5 mm air gap : 7

TALAT Training in Aluminium Application Technologies	Typical Fixing Method for Gypsum Boards for Beams (left) and Columns (right)	2503.04.05

2503.05 References/Literature

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