

R108

THE FIRE RESISTANCE OF ALUMINIUM

Introduction

This article presents a comparison between the fire performance of aluminium and steel. The comparison is made by reference to two designs for a 100m link bridge between an accommodation and production platform. One design is constructed of aluminium and the other is a conventional steel design. The temperature time histories for the primary supporting members in the two cases are presented for identical loading conditions.

The thermal response behaviour of two sample panels representative of radiation shield, cladding, pressure relief panels or unprotected fire wall panels is also compared.

Material Properties

The relevant mechanical and thermal properties of aluminium and steel are given in Table 108.1. The figures are given for two alloys of aluminium.

There are clear weight advantages to be gained by the use of aluminium resulting from its lower strength/density which is about twice that of steel for the 6082 variant. The stiffness/density of aluminium 6082 is about the same as that for steel. This has been accepted for a long time in the offshore industry but the thermal performance of aluminium has been considered to be one of the main stumbling blocks restricting its use. Other aspects of the material as a candidate for use in fire and blast protection are discussed in Reference 108.1.

Figure 108.1 demonstrated the degradation of strength of both aluminium and steel with increases in temperature. From this curve a suitable maximum working temperature for aluminium would be about 200°C whereas for steel an equivalent temperature would be 500°C. Figure 108.2, from References 108.2 and 108.3, shows a comparison of the stress/strain curves for steel and aluminium at different temperatures. The curve for steel at say 300°C corresponds in shape to that for aluminium at room temperature, as the well defined yield point is spread. In this sense aluminium may be considered to be a material similar to steel but with an intrinsically high temperature.

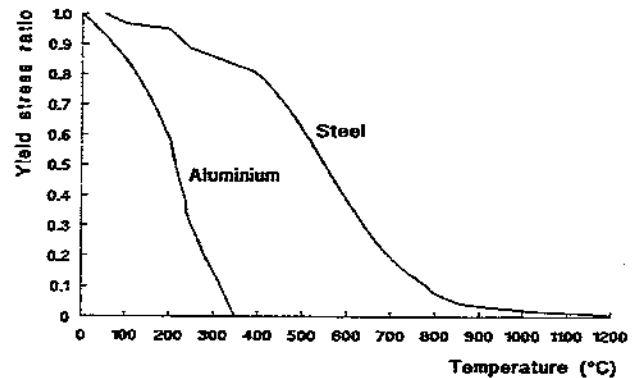


Figure 108.1
Reduction of yield stress with temperature.

The curves given in Figure 108.1 are somewhat misleading and give an unfair comparison on their own. The actual temperature attained by a particular structural member or panel will depend on other parameters.

Example calculations

The suitability, or otherwise, of aluminium for use in structures designed to resist thermal loading is discussed in this section by considering two examples.

Primary Members

A bridge is required to link an accommodation platform to a process platform. The bridge span is of the order of 100m and consists of a triangular truss with the apex along the top chord. The bridge is required to withstand an incident flux of 16 kW/m² from the process platform (non-engulfed case) and a sea pool fire (engulfed case) under the bridge for about an hour.

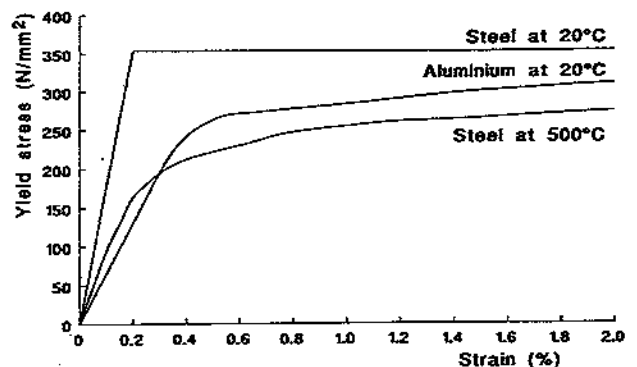


Figure 108.2
Stress/strain ratio curve for aluminium and steel

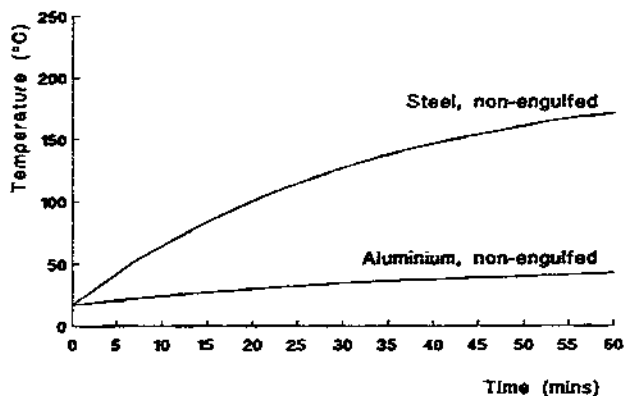


Figure 108.3
Temperature-time history Steel vs. Aluminium
Non-engulfed members case

A typical steel tubular for the bridge is a 457mm O.D. member with a 20mm wall thickness. The equivalent aluminium (6082) member would be a 432mm O.D. member about 35mm thick to withstand the same bending moment at mid span, giving a weight saving of 44%. This is unfair to aluminium as the bridge would be lighter and hence the mid-span bending moment would be reduced. It is also likely that an extruded box section would in fact be used.

For the case of an incident flux q_{ir} W/m², the non-engulfed case, the heat accumulation equation or unit length of the member may be written:

$$\epsilon q_{ir} \times H_p \delta t - \epsilon \sigma T_s^4 P \delta t = \rho C A \delta T_s \dots\dots\dots (1)$$

Where

- H_p is the heated perimeter (m)
- P is the total perimeter (m)
- δt is the time interval considered (s)
- T_s is the member temperature (°K)
- A is the cross sectional area of member (m²)
- δT_s is the increment of member temperature in time δt (°K)
- σ is the Stefan-Boltzman constant. ($= 5.67 \times 10^{-8}$ W/m²/°K)
- ϵ is the emissivity

The other variables are defined in Table 108.1.

Neglecting the flux radiated away from the member gives the rate of change of member temperature with time as:

$$\delta T_s / \delta t \approx \epsilon q_{ir} H_p / (\rho C A) \dots\dots\dots (2)$$

Use of the material properties in Table 108.1 shows that the rate of increase of temperature of the steel member is 4.5 times as fast as that for the aluminium member. This is due to the low emissivity of aluminium, the thermal capacities of the members are similar. The temperature time curves for both the steel and aluminium members are given in Figure 108.3 for an incident flux of 16,000 w/m². Re-radiation from the member surface is included in calculating these curves. After an hour, the aluminium will have reached only 41°C whereas the steel bridge will be at 171°C.

For the engulfed case, representing a pool fire on the sea, the incident flux is proportional to the fourth power of the flame temperature. If the re-radiation from the member and convection are neglected, then the rate of temperature rise may then be written:

$$\delta T_s / \delta t \approx \epsilon \sigma T_f^4 P / (\rho C A) \dots\dots\dots (3)$$

In this case the rate of increase of temperature of the steel member is 7.2 times that for the aluminium member, due mainly to the reduced emissivity of aluminium. After 5 minutes the aluminium bridge will be at only 79°C. Both the steel and aluminium bridges will have failed after one hour, although a sea-pool fire of this duration is a very severe case.

Panel Response

In this section, the thermal response behaviour of a typical steel cladding panel with a thickness of 5mm (3/16") is compared with the equivalent aluminium panel of the same thickness.

A steel or aluminium panel is acted upon by a thermal flux of q_{ir} W/m², this is the non-engulfed case. The rate of temperature rise of the panel is given by Equation (1) with the heated perimeter H_p set to unity and the perimeter P set to two and with the area A replaced by the thickness. It is now important to include the re-radiation and convection from the back surface.

The temperature time curves for both panels are given in Figure 108.4. Re-radiation from both faces and convection from the back face is included.

For the engulfed case where the panels are in contact with the flame at temperature T_f , taken to be 1000°C, the governing equation may be derived from (1) with the incident flux equal to $\epsilon \sigma T_f^4$.

The engulfed aluminium panel reaches over 300°C within 5 minutes, the steel panel reaches 750°C in the same time. Both materials have lost the same proportion of strength by this time. After an hour the aluminium panel has melted but the steel panel's temperature only rises a few degrees more and if unloaded it may survive.

Table 108.1
Mechanical and Thermal Properties of Aluminium and Steel

Material	Mechanical Properties			Thermal Properties		
	Density ρ (Kg/m ³)	Young's Modulus (kN/mm ²)	Tensile Strength (N/mm ²)	Specific Heat C (J/Kg °C)	Conductivity K (W/m °C)	Emissivity ϵ
Carbon Steel 50 D	7850	210	355	500	50	0.8
Aluminium 6082 - T6	2710	70	255*	900	130	0.11
Aluminium 5454 - M	2710	70	110*	900	130	0.11

* 0.2% Proof Stress

Thermal Properties are averaged over the temperature range

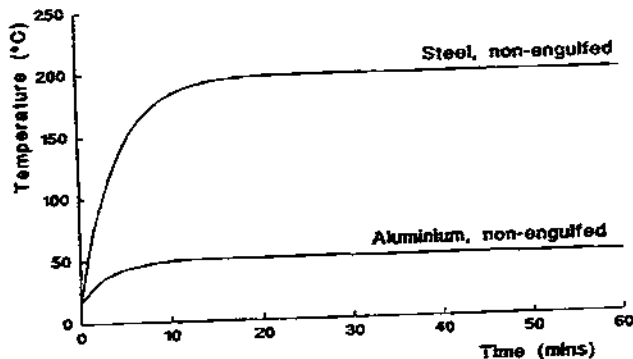


Figure 108.4
Temperature-time history Steel vs. Aluminium
Non-engulfed panels

Conclusions

Aluminium members survive well in non-engulfed conditions and will stay cool longer. In the engulfed case, steel members will generally survive longer.

Aluminium panels operate well in non-engulfed conditions due to their low emissivity and so are suitable for use as heat shields.

Aluminium panels may melt if engulfed or in contact with flames as radiation from the back face is limited. Steel panels seem more suitable in these conditions.

Further Details

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