TECHNICAL REPORT

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Aluminium structures — Material and design — Ultimate limit state under static loading

Structures en aluminium — Matériaux et conception — État limite ultime sous charge statique

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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 11069, which is a Technical Report of type 1, was prepared by Technical Committee ISO/TC 167, *Steel and aluminium structures*, Subcommittee SC 3, *Aluminium structures*.

This Technical Report was proposed as a Draft International Standard but failed to obtain the required committee support. Reasons for the failure were primarily concerned with the attempt to promote the standard prepared by the ECCS. There was no serious technical disagreement; thus the grounds for the lack of support could not be resolved by addressing the technical content.

Aluminium finds wide application in load-carrying assemblies, such as building structures, vehicles and ships, to which the rules for strength design have general validity. This Technical Report deals with the resistance of aluminium structural elements, without regard to any specific product. Because of this broad target, such standards as those developed for steel in particular markets cannot provide a model. No single European standard is suitable for international acceptance; therefore the procedures presented are compromises to satisfy the demands of both Europe and North America.

National standards include the required safety levels for the particular field treated. Because there is no specific field considered in the Report, there can be no values given for resistance factors or other safety margins. However, if the load spectrum and desired reliability are known, safe design procedures are readily obtained using the resistances provided.

Being intended for international use, no purpose is served by further delaying the issuing of the Report by waiting for the final ECCS recommendations, or the conflicting British Standard BS 8118, or the very distant CEN code for aluminium structures.

Design procedures have been based on the current techniques used for steel structures, adjusted to suit aluminium, and the presentation will be familiar to those using modern steel codes of practice, but may differ in some respects from the methods of earlier aluminium standards.

The Commentary to the Report gives only a limited review of the sources of the treatments proposed. Over the 16 years that the Committee has been meeting, a great deal of material has been produced which records the many aspects of each of the subjects that have been examined, and reveals the areas where compromise has been needed.

Annexes A and B of this Technical Report are for information only.

Introduction

Limit states design requires a knowledge of the ultimate load capacities of components and of the distortion of structural assemblies under the action of specified service loads. These two aspects of structural behaviour are in most cases unrelated and require independent treatment.

This Technical Report gives the ultimate load capacity of aluminium members and connections used in stressed applications, under the action of static loads. The types of component treated include bars, plates and panels; the types of connection are riveted, bolted and welded.

Under the action of static loads, some local buckling and local yielding, up to fully plastic behaviour, are acceptable prior to the attainment of the ultimate resistance.

No restriction is placed on the fields of application, as, in this Report, the component is treated in isolation from its use.

In every application, one design criterion is that the resistance of the part exceed the load effects. To ensure this in limit states design, the load is increased by a "partial factor on load" (load factor), and the ultimate resistance of the component is decreased by a "partial factor on resistance" (resistance factor). These factors, in combination, provide the desired reliability index for the assembly. As each application has its own load spectrum and required level of security, no general values for the partial factors are possible, and are thus not included in this Report. International Standard ISO 2394 deals with the manner in which suitable partial factors are to be determined.

Characteristic resistances obtained using this Report are, in general, the mean of test results less two standard deviations. The values may be factored to provide "safe", "working" or "rated" capacities in those applications which do not use limit states design.

Deformation and natural frequencies of components and assemblies are limited by the need to meet the dictates of the intended purpose. Such serviceability requirements are not treated in this Report.

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Aluminium structures — Material and design — Ultimate limit state under static loading

1 Scope

This Technical Report provides design expressions to determine the characteristic values for the ultimate resistances of components and connections in aluminium assemblies which are subjected to known static forces.

It is intended for general applications of structural aluminium alloys other than those used in aircraft and for other special purposes. All wrought product types are included, in all thicknesses suitable for load-carrying.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Technical Report. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Technical Report are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 2394:1986, *General principles on reliability for structures.*

ISO 3898:1987, *Bases for design of structures — Notations — General symbols.*

ISO 8930:1987, *General principles on reliability for structures — List of equivalent terms.*

3 Symbols

The preferred symbols used in this Technical Report are based on ISO 3898 and ISO 8930, and are as follows:

a	dimension, weld throat	A	area
b	dimension		
c	distance	C	constant
d	distance, diameter		
e	eccentricity, edge distance	E	elastic modulus
f	stress		
$\bar{f}$	normalized buckling stress $= f_c/f_o$	F	action
g	fastener spacing, gap	G	shear modulus
h	web depth	H	length
i	radius of gyration	I	moment of inertia
k	factor	K	factor
		L	length
m	factor, number	M	moment
n	number	N	force
r	radius	R	resistance
s	fastener spacing, stiffener spacing		
t	thickness	T	torque
v	shear flux	V	shear force
w	width	W	section modulus
x	distance		
y	distance		
z	weld size		
α	factor, index, coefficient of thermal expansion	β	factor, angle
γ	partial factor	δ	imperfection
λ	slenderness	θ	angle
ν	Poisson's ratio	$\bar{\lambda}$	normalized slenderness $(f_o/f_e)^{1/2} = (\lambda/\pi)(f_o/E)^{1/2}$
η	ratio	ρ	density

The following suffixes are used:

b	bearing
c	compression, critical
d	design
e	elastic, Euler
f	factored, flange
g	gross
h	HAZ (heat-affected zone)
k	characteristic
l	lateral
m	maximum, material
n	net, normal
o	limiting
p	plastic, polar
r	resistance
s	shear
t	tension, torsion
u	ultimate
v	weak axis of angles, shear
w	warping, welded, web
x	axis (major)
y	yield, axis (minor)
z	axis

4 Documentation

4.1 Calculations

Calculations of the resistance of a component or connection shall include the alloy designation and temper, the guaranteed mechanical properties and any derived properties that are used, together with a complete geometric description of the component or connection, and the support conditions. Where the resistance is influenced by associated components, they shall also be fully described.

4.2 Testing

If the resistance is determined by testing, information shall be given on the method of support and load application, the number of tests, the number of parameters varied, the locations of points where strains or deflections are measured, the force/displacement relationships, and the mode of failure. Coupons shall be cut from the test specimens and the mechanical properties determined.

This information shall be sufficiently complete that a third party may interpret the results, and arrive at values for the characteristic resistances which relate to the probable strengths of the components with the same confidence as those predicted by the design expressions in this Technical Report.

5 Basic design principles

5.1 General

Components and connections are proportioned to provide a required ultimate resistance, and to perform within specified limits under service loads. All conditions arising during manufacture, transportation, assembly and construction, and the intended life in service, shall be considered in determining the suitability of the part.

5.2 Limit states

Limit states are classified as "serviceability" limit states and "ultimate" limit states.

Serviceability limit states are dictated by the function of the assembly and are treated in standards specific to the application.

Ultimate limit states are a matter of public concern. They correspond to the highest force that members, connections, assemblies or complete structures can sustain without uncontrolled distortion. The limit may be set by the need to avoid

- large deformations due to extensive yielding;
- rupture, including that due to fatigue;
- member instability;
- overall instability.

Deflection and other distortions, except insofar as they influence stability, are not considered at the ultimate limit state.

While such failure modes as overturning and foundation or anchorage failure need to be considered, they are not treated in this Technical Report, which is restricted to aluminium parts.

5.3 Design requirement

The joints, components and assemblies shall be proportioned to satisfy the inequality:

$$S_d \leqslant R_d$$

where

S_d is the design action (internal force) due to the factored load;

R_d is the design resistance (factored resistance).

5.4 Design load

Knowing the load spectrum for a particular application, characteristic loads are selected, usually based on a required return period.

The design load, F_d, is the product of the characteristic value of the load, F_k, and the partial factor on load (load factor), γ:

$$F_d = F_k \gamma$$

Values of γ are given in the applicable national standards.

The design action (internal force) is obtained from the analysis of the assembly when subjected to the design load (factored load), and is used to determine the required design resistance (factored resistance) of a component.

The design actions are expressed as follows:

N_{sd} is the design force

V_{sd} is the design shear force

M_{sd} is the design moment

T_{sd} is the design torque

5.5 Design resistance

The expressions provided in this Report give the values for the characteristic resistances, R_k.

The design resistance (factored resistance), R_d, is obtained using

$$R_d = R_k/\gamma_m$$

in which γ_m is the partial factor on resistance (resistance factor).

Values of γ_m are established for each particular application in conjunction with the partial factors on load (load factors), γ, to provide the required level of reliability. When values are not given in national standards, ISO 2394 provides guidance.

Predictors given in this Report have been targeted to give values for the characteristic resistance that are the mean value from test results less two standard deviations.

6 Basic considerations

6.1 Static actions

Characteristic values for the actions, to be used in the design, are specified in the standards appropriate to the application.

Direct actions are loads such as the weight of cargo, wind pressure and traffic. They may be static, quasi-static equivalents of impact forces, temporary, permanent, fixed, variable, planned or accidental. The type of action will determine, in part, the partial factor to be applied.

Indirect actions are those attributed to imposed changes in geometry such as are caused by expansion and settlement. In general, indirect load effects are to be avoided by using a suitable overall design, as, in normal circumstances, they are not readily predictable.

6.2 Materials

6.2.1 Aluminium alloys

In selecting an aluminium alloy for a stressed application, its suitability will be assessed on the basis of conformity to an International Standard, or European or national standard and on the following considerations, as applicable:

- strength: yield and ultimate;
- ductility: elongation and reduction in area;
- weldability and welded properties;
- corrosion resistance in the intended environment;
- formability;
- machinability;
- surface finish.

In general, extrusions will be of heat-treated alloys in T5 or higher temper, while sheet and plate may be of heat-treated or work-hardened alloys.

Where castings or forgings are to be used, there shall be close cooperation with the suppliers to establish the design properties. For foundry alloys, the values should be confirmed by tests of the finished casting.

6.2.2 Fasteners

Only bolts and solid rivets are treated in this Technical Report. Bolts may be of aluminium alloy, zinc- or cadmium-coated steel, or stainless steel. Solid rivets will preferably be of an aluminium alloy. If proprietary fasteners are used, the value of the ultimate resistance shall provide the same level of reliability as do connections proportioned according to this Report (see 6.4.2.1).

6.2.3 Welds

Welding electrodes and filler wire, and shielding gas shall be selected to suit the alloys to be joined and the method of welding (see clause 15).

6.2.4 Identification of material

All material shall be marked or stored such that the identification of the alloy and temper can be established at all stages of manufacture.

6.3 Geometrical parameters

Dimensions of profiles, members and overall assemblies shall be subject to the ruling commercial tolerances applicable to the product.

6.4 Properties

6.4.1 Physical properties

For strength design purposes, all aluminium alloys to which this Report applies shall be considered to have the following physical properties:

Elastic modulus, E	70 000 MPa
Elastic shear modulus, G	26 000 MPa
Poisson's ratio, ν	0,33
Density, ρ	2 700 kg/m^3
Coefficient of thermal expansion, α	0,000 024 per 1 °C

6.4.2 Mechanical properties

6.4.2.1 Specified properties

Yield strength, f_y, (0,2 % proof stress) is taken to be that stress in tension at which there is a 0,2 % strain offset in the stress/strain relationship.

Ultimate strength, f_u, is the highest force in tension, sustained by the test specimen, divided by the original cross-sectional area of the specimen.

Yield and ultimate strengths in tension are the basic mechanical properties specified, for each alloy and temper, in International Standards, or European or national standards. (To satisfy the requirements of the Aluminum Association, the values are expected to be exceeded in 99 % of the production, at a confidence level of 0,95.) Selected values of these strengths for some popular alloys are given in table A.1.

Yield strength in compression, yield and ultimate strengths in shear, and strength in bearing, may be established by a sufficient number of tests to provide the same level of confidence as that for the specified properties. When these values are not available, 6.4.2.2 shall be used.

6.4.2.2 Derived properties

6.4.2.2.1 Yield strength in compression

In compression, the yield strength shall be taken as the value in tension.

6.4.2.2.2 Yield and ultimate strengths in shear

For direct shear, the characteristic strengths shall be taken to be

— yield strength in shear, $f_{vy} = 0{,}6 f_y$

— ultimate strength in shear, $f_{vu} = 0{,}6 f_u$

6.4.2.2.3 Ultimate strength in bearing on fasteners

For bolts and rivets acting in bearing, the characteristic bearing strength of the connected material shall be taken to be

$$f_{bk} = 2 f_u$$

This is subject to the further restrictions given in 14.3.2.

The bearing stress on the fastener itself need not be considered.

6.4.2.3 Welded properties

Full account shall be taken of the influence of welding on the properties of aluminium, as described in 8.2.

Table A.1 gives, for some popular alloys, the values of the yield and ultimate tensile strengths of the base metal and of the metal in the heat-affected zone (HAZ) at the weld, which are acceptable for design purposes.

Table A.2 gives, for some popular alloys, values for the ultimate tensile strengths of the weld beads which are acceptable for design purposes.

Higher values may be used if they are demonstrated and can be ensured in production.

When the properties of the heat-affected zone (HAZ) are not known, they may be taken to be equal to those in the solution-treated condition for heat-treated alloys and equal to those in the annealed condition for work-hardened alloys. Because the properties of the weld bead are a function of both the base metal alloy and the filler wire alloy, any combination for which the properties are not known shall be tested to establish the strength of the weld bead itself.

7 Methods of analysis

7.1 General

For individual components and connections, the design expressions in this Report give the ultimate resistance. Behaviour may be linear or non-linear. The values obtained are not related to the method of analysis; however, as the behaviour of individual parts can influence the overall behaviour of the assembly, the method of analysis may take cognizance of the force/deformation relationships of the components.

7.2 Elastic analysis

Elastic analysis is generally considered to provide a lower bound solution, and is permitted for all assemblies, without regard for the behaviour of the individual components up to the ultimate resistance, unless geometric distortions influence the stability of the assembly.

7.3 Plastic hinge analysis

Plastic hinge analysis may be used for rigid frames in which it can be demonstrated that the required rotation at the yield hinges is available, and the destabilizing influence of compression forces is taken into account. The limited deformation capacity at bolted joints and transverse welds shall be considered when determining whether plastic hinges can be developed.

7.4 Yield line theory

Yield line theory for plates may be used, but full account shall be taken of the influence of any welds or perforations for fasteners.

7.5 Redundant lattice structures

Non-linear analysis of redundant lattice structures is permitted only where the force/deformation relationships for the components are known and can be accurately or conservatively modelled.