September 2011

DVS – DEUTSCHER VERBAND FÜR SCHWEISSEN UND VERWANDTE VERFAHREN E.V.

Design and strength assessment of welded structures from aluminium alloys in railway applications

Technical Code DVS 1608

Replaces May 1983 edition

This technical code is the revised version of the technical code DVS 1608 from May 1983. The revision was initiated to incorporate the new requirements for the assessment of weld performance classes imposed by EN 15085 – taking into account the strength- and safety requirements for welded joints in railway vehicle design. The notch stress concept has been included as a method of evaluation in addition to the nominal stress concept. The procedure to prove static strength has been incorporated as well.

The validity of this technical code has to be agreed between supplier and contracting body.

The technical code was written by representatives of the railway vehicle industry, of "DB AG", of the "Eisenbahn-Bundesamt (EBA)" and of "IMA Materialforschung und Anwendungstechnik GmbH Dresden".

Content:

1 Introduction

This technical code contains recommendations for design and specifications for the design of welded constructions of aluminium alloys as well as a comprehensive table of different types of welded joints (structural details) that are established in railway vehicle design in reference to safety, operability, lightweight design, economic assembly and maintenance.

The procedure to verify the static strength and the fatigue strength of base material and of welded joints is described.

A structural detail catalogue has been prepared for the proof of the endurance strength using the nominal stress concept. In this catalogue, joint details are assigned to the weld performance classes according to DIN EN 15085-3 and to the structural detail

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curves or endurance strength values which have resulted from the revision of the DVS 1608:1983 and which are also an integral part of this technical code. Together with the consideration of different safety categories the requirements of DIN EN 15085 are fulfilled.

The endurance strength limit values relate to the base material as well as to welded component joints in railway applications and to the load assumptions and manufacturing conditions applicable here. That must be considered if these endurance strength values are applied in other fields. The catalogue for welded joints in Appendix B does not make any claim to be complete.

In addition to the nominal stress concept the notch stress concept is introduced as a method for evaluation.

S-N curves (Woehler curves) are given for the fatigue strength verification for the nominal stress concept as well as for the notch stress concept. Thus, an evaluation of the fatigue strength, respectively of the operational durability, based on the cumulative damage approach is enabled.

This technical code is to help structural and design engineers to design welded joints in a way that loads are efficiently sustained by the structure. Additionally, this guideline supports welding and quality assurance engineers for quality and welding issues.

2 Scope

This technical code applies to the design and evaluation of static and fatigue strength in base material and arc welded joints of aluminium alloys used in railway applications, which are listed in the series of standards DIN 5513 as well as DVS 1623. This technical bulletin has to be applied in designs with wall thicknesses of $t \geq 1.5$ mm.

The following alloys are suggested for railway applications:

- Extruded profiles:
  EN AW-6005A, EN AW-6082, EN AW-6060, EN AW-6106
- Sheets, plates and strips:
  EN AW-5083, EN AW-5454, EN AW-5754, EN AW-6082
- Aluminium casting:
  EN AC 21000, EN AC 42000, EN AC 43300, EN AC 51300
- Forgings:
  EN AW-5754, EN AW-5083, EN AW-6005A, EN AW-6082.

Semi-finished products made from the alloy EN AW-7020 (AlZn4.5Mg1) show an inherent risk with respect to stress corrosion cracking and to exfoliation corrosion sensitivity.

The design conditions of railway vehicles and the uncertainties due to the influences during operation require that the recommendations of the aluminium producer in reference to the manufacturing methods and to the methods of corrosion protection (e.g. anodizing, coating, painting, heat treating) are strictly followed if the alloy EN AW-7020 is used. Therefore, the use of alloy EN AW-7020 is not recommended for new designs.

If new materials or other wall thicknesses are used, it is necessary to check the applicability of the strength stipulations included in this technical code.

3 Weld process in production and quality assurance

For the design of welded joints in railway applications the requirements of DIN EN 15085 shall be considered.

The design drawings shall be generated following the requirements of DIN EN 15085-3 and of the technical bulletin DVS 1610.

Note:
When adapting drawings of existing welded designs, that were created according to withdrawn regulations (e.g. DIN 6700), to DIN EN 15085, the requirements of the technical bulletin DVS 1623 have to be met. This requirement especially applies when updating the weld performance class and the related inspection class to prove the weld quality (e.g., NDT).

According to DIN EN 15085 a welded structure in railway applications has to meet the requirements of weld ability according to DIN 8528-1. In detail the following applies:

- The weld ability of the materials is given if the requirements of the standards of DIN EN 15085-3, chapter 6.1., are met.
- The weld ability of the welding filler material is given, if these filler materials are qualified and selected for the particular material according to DIN EN 15085-4, chapter 5.3.
- The welding security of the design is given, if the design withstands the loadings in reference to the material behaviour. The requirements of DIN EN 15085-3 and DIN EN 15085-4 have to be met.
- The welding ability in the fabrication is guaranteed if the structure is manufactured while paying attention to the certification level and to the welding processes possible in the plant.

In addition to the weld ability of the design, it is also necessary to assure that the design allows for inspections (prescribed non-destructive evaluation methods have to be possible) and for proper maintenance according to DIN 27201-6 (see also technical bulletin DVS 1620).

The stipulations of DIN EN 15085-2, Appendix A, apply to the assignment of the components and the parts to the certification levels. For the classification of the welded joints to the weld performance classes, Section 8 of this technical code includes simplified definitions with which the stipulations of DIN EN 15085-3, Table 2, are fulfilled. Furthermore, details for specifying the safety requirements are listed, which comply with DIN EN 15085-3, Appendix G.

Note:
It is important to consider that the categorization of the weld performance class also implies the categorization of the certification level of the components, because the certification level primarily depends on the weld performance class according to DIN EN 15085-2.

Welded designs in railway application complying with DIN EN 15085 are subjected to a weld inspection according to technical bulletin DVS 1620.

3.1 Planning of weld process and design-related recommendations

In the design of welded railway vehicles the manufacturability of the weld joints has to be checked together with the welding engineer.

Welding sequence plans have to be created for complex designs (see technical bulletin DVS 1610).

The weld joint types as well as the requirements with respect to the weld performance class and the inspection effort are to be defined together by the design engineer, the structural engineer and the welding engineer.

3.2 Requirements for production facilities

The workshops in which aluminium is processed must be spatially separated from those in which there are any dusts, gases or fumes which may exert a detrimental influence on the corrosion resistance of aluminium or on the weld quality. If welding is used for any repair activities on the load-bearing vehicle structure, it is necessary to use suitable clamping jigs.

In analogy to the technical code for the workshops, a room temperature of at least 12°C must be guaranteed for the welding of aluminium alloys.

The temperature must be prevented from dropping below this minimum value for the following reasons:

- the manual skills of the welders are restricted,
- higher shrinkage stresses increase the risk of cracking,
- the parameters confirmed at the normal temperature in the welding procedure specifications are no longer assured due to worse penetration behaviour,

Increased condensation water formation may give rise to porosity during welding.

3.3 Tools and jigs

All tools shall solely be used on aluminium materials or they have to be thoroughly cleaned before use (they must be free of any remains of other metals).

Jigs and fixation equipment made from steel should show clean clamp surfaces that are free from rust. As an alternative, a suitable interlayer may be used, for example made of aluminium, stainless steel or plastics. The interlayer shall be free of copper.

Transport containers and storage shelves shall be designed with rust protection (e.g., zinc coated) or shall be lined with chlorine-free paper or dry wood. Cleaning brushes shall have bristles made of stainless chrome-nickel steel and shall be clean and free of grease.

3.4 Cleaning and degreasing

The components to be welded shall be cleaned from grease, dust and coatings mechanically or by suitable chemical agents (for example acetone).

3.5 Weld preparation

The weld preparation should preferably be made using mechanical tooling (e.g., milling). A form cutter should be preferred for the elaboration of the root. The usage of resin bonded grinding wheels may lead to porosity on the weld seam, if plastic abrasion remains in the weld groove faces. The joint forms are listed in DIN EN ISO 9692-3. Further recommendations on the joint forms are given in DIN EN 15085-3.

3.6 Tack welding

Tack welds that remain in the joint shall be performed in a way that the quality requirements of the finished weld joint are met. Tack welds should be avoided or be carefully removed in highly stressed areas. If necessary, tack sequence plans are to be provided with that information.

3.7 Preheating

Depending on the work piece dimensions and on the welding process, preheating may be required in the region where the welding begins. The preheating should be carried out with the lowest possible uniform energy input (soft flame with propane/butane gas and sprinkler attachment for initial heating). The preheating temperature shall be monitored with temperature measuring devices. The preheating temperature should not usually be higher than 150°C.

3.8 Welding procedures, filler materials and shield gases

In rail vehicle construction, preference is given to the application of gas-shielded arc welding processes such as TIG and MIG welding and their variants. Before beginning or resuming the welding, the groove faces, the weld region, the tacks or the intermediate layers shall be cleaned carefully. End crater cracks, lack of fusion and cracked tack welds shall be machined out carefully.

In the case of MIG welding, lack of fusion and end crater cracks at the start and end of the weld can be avoided using run-on or run-off plates. If this is not possible, the arc should be ignited on a sheet located next to the weld. At the end of the weld, the arc must be guided back on the weld and the arc must end on the weld. If the welding work is interrupted, the welding speed must be increased so that the finish of the weld ends in a wedge shape. In the case of TIG welding, the end crater can be filled, for example, by lowering the welding current.

In principle, not only the gas-shielded arc welding processes but also other welding processes such as laser welding or friction stir welding are authorised but the strength assessment of these higher-strength welds shall nevertheless be made with the permissible values of the gas-shielded arc welding process if repair measures are made with gas-shielded arc welding processes after accidents or modifications. This shall already be taken into account during the basic dimensioning.

Only suitable welding fillers shall be used. Preference shall be given to the AlMg4.5MnZr (S Al 5087), AlMg4.5Mn0.7 (S Al 5183A) and AlMg5Cr (S Al 5356A) welding filler materials or to comparable filler materials, as listed in the DVS 1623 technical bulletin, Appendix 2, table 3.

The AlSi5 (S Al 4043A) welding filler material may be used only in exceptional cases and only after clarification with the welding supervisor. The minimum values for the strength of aluminium welding fillers are specified in Table 2. In general, argon, helium and helium-argon mixtures according to DIN EN ISO 14175 are used as shielding gases.

Notes about the assignment of the welding fillers for selected aluminium and aluminium alloys are given in the DVS 1623 technical bulletin, Supplement 1, Appendix 2, table 3.

3.9 Heat treatment after welding

In general, a heat treatment after welding is not required.

In the case of hardening alloys, certain material properties (e.g., strength and corrosion resistance) can be improved by artificial ageing after welding.

3.10 Straightening of welded components

Welded components may be straightened in warm or cold conditions. During this procedure cracks (structural damages) shall not occur.

In the case of hot straightening, preference shall be given to the deposition of straightening welds on already existing welds or in the immediate web region of extrusion profiles. Straightening welding areas shall be evaluated with the corresponding strength values of the welds. For static analyses the strength values of the heat-affected zone shall be used. For fatigue assessments the corresponding structural details for the welds shall be used.

Flame straightening of aluminium components should be avoided, since the heat input cannot be controlled thoroughly enough in working environment. A local increase of temperature beyond 150°C can lead to disadvantageous strength reduction at certain aluminium alloys.

If flame straightening is nevertheless applied, the temperature should be monitored with measuring devices. Furthermore, the flame-straightened regions shall be assessed structurally with the correspondingly decreased strength values (heat affected zone). Flame straightening may only be carried out in the permitted straightening zones.

The possible straightening zones shall be assessed structurally and shall be specified by the vehicle manufacturer.

For flame straightening, it is necessary to comply with the DVS 1614 technical bulletin.

3.11 Specification for zones prohibited for welding

Welding-prohibited zones are areas where any additional weld joints – for example straightening welds, holders, electrical grounding attachments, etc. – shall not be applied without approval of the structural engineer. It is recommended to define all the welding-prohibited zones in a drawing.

In welding-prohibited zones grounding clamps shall not be attached during welding.

The definitions of welding prohibited zones can be used for maintenance and repair issues after accidents.

3.12 Maintenance and repair

The standard DIN 27201-6, (State of railway vehicles – Basic principles and production technology – Part 6: Welding) shall be applied for maintenance welding procedures on rail vehicles.

Any maintenance weld shall be evaluated and structurally approved by a structural engineer. A repair instruction has to be elaborated and approved by the welding supervisor.