Basis for fatigue design of aluminium

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Basis for Fatigue Design of Aluminium

Bases pour le dimensionnement à la fatigue des constructions en aluminium

Grundlagen für Berechnungen von Aluminium bei Ermüdungsbeanspruchung

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SUMMARY

Fatigue design by empirical rules is no longer accepted as being efficient or safe for present day applications. However, at an international level, a unified, widely applicable and accepted approach is only just beginning to take shape. Elements and concepts of the new ECCS draft for fatigue design in aluminium are presented in this paper.

RESUME

Le dimensionnement à la fatigue basé sur des règles empiriques n'est plus acceptable, car il n'est ni économique ni du côté de la sécurité. Un procédé unifié, largement applicable et admissible, commence à prendre forme, même sur le plan international. Les éléments et concepts du nouveau projet CECM pour le dimensionnement à la fatigue des constructions en aluminium sont présentés.

ZUSAMMENFASSUNG

Die Dimensionierung schwingbeanspruchter Bauteile auf der Grundlage einer empirischen Anpassung ist keine akzeptable Methode für neue Entwicklungen, da sie weder leistungsfähig noch sicher ist. Ein einheitliches Vorgehen, breit anwendbar und annehmbar, beginnt erst jetzt feste Form anzunehmen, nun auch auf internationaler Ebene. Bestandteile und Hilfsmittel eines neuen EKS Entwurfs für schwingbeanspruchte Aluminiumkonstruktionen werden dargestellt.

1. INTRODUCTION

Our efforts to develop specifications for the design of aluminium structures in the last thirty years have been characterized, naturally, by the fact of a fluctuation between theoretical and experimental research, drafting recommendations and experience in practice.

Viewing the special problem of specifications for the fatigue design of aluminium structures we will recognize that in respect to research after a period of reconnaissance in the sixties and early seventies - i. e. small specimen testing, fundamentals of test planning and data evaluation - as well as a period of consolidation of our knowledge in the seventies - with more specimen testing filling in the blanks and statistical reevaluation of test data - we have now entered in the eighties a period of full-scale component fatigue behavior testing and application of knowledge to specifications, the latter for the first time on an international scale [1].

In respect to codes it seems that about every decade new efforts are undertaken to define in specifications the design of aluminium structures in fatigue. A review of several national proposals is given in [2] along with a brief analysis and comparison of relevant elements [3]. Two years ago work was initiated on committee T2 of the ECCS towards european recommendations for fatigue design, following the first issue of the respective recommendations for statically loaded structures [4, 5]. This is the framework with which most of the national and international activities concerning applied research and development of fatigue design concepts for aluminium structures will have to orientate.

2. CODE DRAFTING AND INTERRELATIONS

Development of standards for welded aluminum structures will have to be in conformity with the corresponding development of standards of steel structures. This is an important fact of the consultations in the last years. So although past experience such as in the ASCE Paper 3341/1962, the british code CP 118:1969 (the most extensive code for aluminium, which is also under revision currently) and elements from the scandinavian codes will have to be taken into account the projected ECCS code will follow parallel developments of the ECCS steel code, the Eurocode 3, Chap. 9 on Fatigue and respective steel codes, here especially DS 804 (German Federal Reilways) and DIN 18800/6, SIA 161 (Switzerland), BS 5400 (UK), AASHTO Specifications (U.S.A.) and the Ontario Code 1979 (Canada). In order to accomplish this goal of multilevel adaptation but in the same time provide for flexibility due to the variety of alloys, production, handling jointing and environmental parameters as well as for future concepts and needs it is imperative that an underlying pattern of theoretical interrelations and pragmatic assumptions will have to be agreed upon. Accepting this pattern beforehand is a rather new approach [6], but we have been working partly towards this direction for aluminium structures since some time [7].

Task Group 4 of the ECCS (chairman Mr. Trüb, Alusuisse, Switzerland), with members form several european countries, representing industry, research and university institutions forms the nucleus. A vivid transfer of experiences with other bodies, as mentioned above, takes place, nevertheless, through numerous affiliations of its members with these committees. The Institute for Steel Structures (ISS) at the Technical University of Munich has been charged with the task to prepare the draft of the ECCS fatigue recommendations.

On the other hand, as mentioned in [7, Ref. 3 - 4 - 5], there exists a background with sufficient data on specimens for most of the typical structural alloys and their jointing methods. In October 1980 a new international "Committee for Aluminum Fatigue Data Exchange and Evaluation" (CAFDEE) was formed in Munich, after the iniative and under the chairmanship of R.A. Kelsey, Alcoa. There are two representatives from each country - one from industry and one from a code making body. The declared purpose is "to collect and analyze fatigue data on aluminium and, when required, recommend tests needed to develop appropriate information, which can be used by the various organizations active in writing design specifications for fatigue loading of aluminium structures and components". A first view of the documentation has been given [9, 10] and we are now going to produce a comprehensive set of fatigue date based on already available information on the Fatigue Data Bank at Iowa State University and recent new data. For this purpose a special questionnaire for registering data on welded or bolted joints has been distributed to potential suppliers of information, Fig. 1.

BASE METAL	STATIC PROPERTIES	BIBLIOGRAPHIC
Alloy / Temper / Treatment Mechanical Properties Chemical Composition	Strength Values Loading Pattern Test Details	DATA CODE
JOINT DESCRIPTION	FATIGUE TEST RESULTS	
Welded Bolted Geometry (Pass sequence)	Stress/ Cycles to Failure (define!)	
	WELDING PARAMETERS	
LOCATION OF FAILURE	Process / Procedure / Treatment	
	WELD QUALITY NDT Testing / Fracture Surface	

Fig. 1 CAFDEE Fatigue Data Questionnaire

In retrieving data parameters such as *alloy* and *temper*, *specimen* and *joint type* must be specified. *Welding procedure*, *special treatment*, *stress ratio* are optional. Probably within the next year the bank information will be made available to the ISS in Munich, where the second stage of statistical and regressional analysis by means of specially developed computer programs along the principles outlined in [1, 2, 7] will take place. Still, since experience shows, that any conflict may arise in the area of data analysis, a subcommittee of CAFDEE will develop a consensus and a methodology on the presentation of fatigue data [11].

Lastly experimental research projects are a further source of information. These involve current investigations in industry and the ISS with (a) full-size welded beams - in accordance with the opening remarks on the relevance of such information - and (b) on crack development and propagation in welded structures.

3. THE ECCS RECOMMENDATIONS

An outline of the first draft [5] was presented in [3, 8] and it is the purpose of this paper to summarize only some of the relevant points, adding comments after the subsequent discussion in ECCS, as well as in relation with some developments in the draft of Eurocode 3. Further work, concerning mainly final assumptions on the data analysis and presentation as well as definition of standard constructional detail cases with respective standardized stress-life design curves, will be dealt with during the presentation of this paper.

The underlying pattern of theoretical assumptions involves a model of the theory of fatigue strength, followed by a model of the theory of damage accumulation, a model of the theory of safety and probability of failure and closes with a specified network of stress-life curves, allowing a unified adjustment of notch and loading cases and materials to "design categories" [6, 2]. Through this unified, yet modular arrangement of parts of the whole, in functional interdependency to each other, one can easily adapt them to corresponding problem areas or future needs.

Fig. 2 outlines the contents of the recommendations.

1 INTRODUCTION
2 PRINCIPLES
3 MATERIALS
4 LOADING
5 STRUCTURAL DESIGN STRESSES
6 FATIGUE STRENGTH
7 SAFETY / RELIABILITY
8 ALLOWABLE STRESSES
9 SUPPLEMENTARY FATIGUE PREDICTION METHODS
10 FABRICATION
CONTROL / INSPECTION
MAINTENANCE

APPENDIX: A - DEFINITIONS / SYMBOLS
B - REFERENCES
C - EXAMPLE ON USE OF DATA ITEMS
D - STANDARD LOAD SPECTRA
E - SCHEME FOR ASSESSEMENT OF RESIDUAL FATIGUE LIFE

Fig. 2 ECCS CT2 Recommendations Aluminium Fatigue

Parts 1 and 2, as mentioned in Fig. 2, do not differ significantly from corresponding specifications for steel. Yet it is intended to provide here recommendations not only for traditional civil engineering structures but also for structures of various sea or land transport means. Relevant parameters for the expression of fatigue strength curves will be alloy dependent, presumably; especially in the lower cycle life areas. (This fact may imply different slopes for S/N-curves). For practical reasons a limit cycle number below which no fatigue assessment is necessary, depending on the field of application and in accordance with static design allowable stresses, will be defined. A similar provision, as a fatigue threshold, may be set up through the applied stress value not exceeding a certain limit. Still these regulations will have to be based on empiricism rather - as a result being somewhat conservative - than on analytical derivation. With more and new information becoming available, through quantitative description of fatigue crack mechanisms this goal seems possible, yet at a later stage. Current projects contribute to this, but will have to be evaluated on a common basis eventually.

Whether there is a significant effect of R-ratio, mean stress or residual stress on fatigue strength must still be judged. There seems to be a mean stress dependency for R-ratios up to ± 0, but still data from different codes is contradictory [3]. An analytical quantification of the residual (mean) stress on fatigue strength, as this is defined by the cyclic stress-strain history on the basis of the critical fatigue notch factor may express the significance of the phenomenon more clearly [12].

The fatigue behavior of aluminium alloy components and weldments at low temperatures may be assumed as identical to that at room temperature.

Relative to loading and fatigue spectra derivation, parts 4 and 5, principles similar to those for steel are adopted. The rain-flow or reservoir cycle counting method is stipulated and spectrum loading data is related to constant loading data by means of Miner's rule (its validity assumed even for different R values). Various spectrum transformations depending on the design purpose are possible.

Depending on the application with a characteristic stress history the definition of a fatigue damage equivalent stress (f.d.e.s.) for one loading event may be computed, thus simplifying design procedures, Fig. 3. Codes then state the f.d.e.s. value for a certain detail and application defined relative to the specification design load spectrum. Differences to the actual load spectrum are expressed by the ratio λ of real to design stresses. For such computations assumptions as to shape and analytical expression of the fatigue strength curve are required.

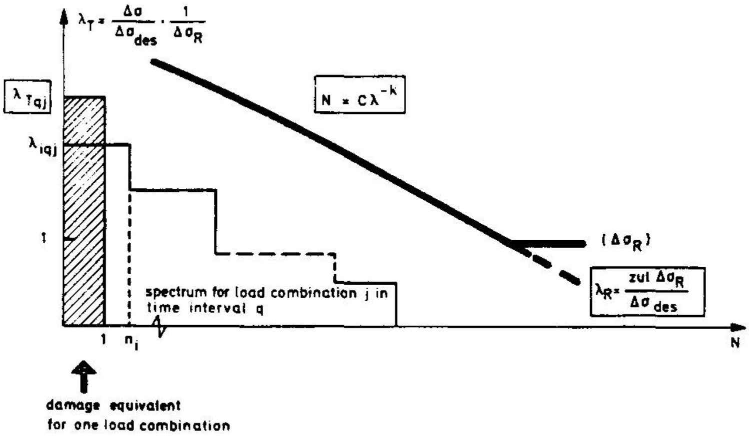

Fig.3 Computing $\boxed{\lambda_{Tqj} = \left[\Sigma n_i \lambda_{iqj}^k\right]^{1/k}}$ the fatigue damage equivalent stress amplitude

(depending on material, notch and component / system characteristics - $\Delta\sigma_R$ - and relative to the specification load spectrum - S_3 ; $\Delta\sigma_{des}$ -)

A definitive presentation of the evaluation of fatigue strength will still have to follow, as already mentioned; yet practically all elements of fatigue data analysis and depiction in form of P-S-N curves have been dealt with amply, as in [1, 6, 7, 8] and numerous other publications. The design elements of the proposed fatigue curves, as given in Fig. 4, also allow an unproblematic adaptation to recent decisious within the Eurocode: slope with a higher value than for steel, transition point respective to endurance limit different from curve reference value. Opinions about the definition of the transition point only in relation with the slope and after accounting for all data points in the 10^6 - 10^7 cycle region [13] conform to former proposals [2] to perform with aluminium fatigue data an optimization of position and slope of the mean

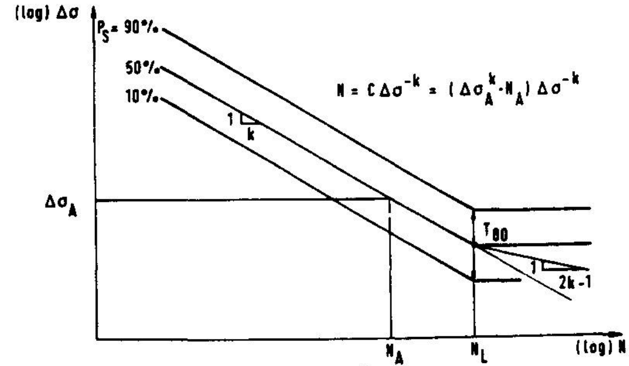

Fig. 4

Reference fatigue life $N_A = 2 \cdot 10^6$; $\Delta\sigma_A$

Endurance fatique life N_L = ?

possibly different for various alloys

Parallel P-S-N curves ; $T_{90} = 1.50$; k = ?

k dependent on alloy (?) and notch case possibly a priori definition

Universal definition possibility through relation $\lambda = \frac{\Delta\sigma}{\Delta\sigma_A}$

Equidistant gradation $\Delta\sigma_{A(m)} = \Delta\sigma_{Ao} \cdot 1.122^{-2m}$

Mean stress σ_m dependence

curve by quantifying run-outs and computing parameters by means of the maximun-likelihood-method. A computer program to be used with the CAFDEE data has been developed at the ISS. Provisions about allowable S-N curves in the Eurocode proposal, as a lower probability of survival range do not include enough background information about scatter etc. - a common coefficient of variation on life cycles has been assumed yet for all cases - so that experimental data cannot be readily correlated. In the case of aluminium, mean curves as well as parallel lower bounds will be given [7, 8]. Thus beneficial design curves could be derived based on experimental evidence.

In the course of classifying standard S-N curves for various structural detail classes (up to six different cases for practical reasons) existing codes - i.e. the british BS 5400 on steel, CP 118 on aluminium, the german DIN 15018, also north american proposals as to a user-oriented display of structural details [1] etc. - and the new Eurocode classification based on well-founded studies of the IIW together with proposals emerging from industrial experience [14] will have to be considered.

It is a remarkable fact that along with similar notions in international codes for steel the ECCS recommendations for aluminium seek to provide for supplementary fatigue prediction or residual life estimation methods. That is, parallel to the conventional semi-probabilistic S-N concept, low-cycle-fatigue concepts for the crack initiation phase and fracture mechanics methods are presented. These methods may be used to classify new or non-classified details within the framework of the tables or to introduce possibilities for failure analysis and assessment of existing or projected structures. The methodology and especially characteristic design values must yet be developed for use in specifications and this is the task of several industrial and university (ISS) research projects. The literature is voluminous on the subject and we only indicate here recent publications concentrating on the applicability to aluminium structures [15, 16].

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