

IIW Collection

Bertil Jonsson
G. Dobmann
A.F. Hobbacher
M. Kassner
G. Marquis

IIW Guidelines on Weld Quality in Relationship to Fatigue Strength



INTERNATIONAL INSTITUTE OF WELDING
A world of joining experience

 Springer

IIW Collection

Series editor

Cécile Mayer, Villepinte, France

About the Series

The IIW Collection of Books is authored by experts from the 59 countries participating in the work of the 23 Technical Working Units of the International Institute of Welding, recognized as the largest worldwide network for welding and allied joining technologies.

The IIW's Mission is to operate as the global body for the science and application of joining technology, providing a forum for networking and knowledge exchange among scientists, researchers and industry.

Published books, Best Practices, Recommendations or Guidelines are the outcome of collaborative work and technical discussions—they are truly validated by the IIW groups of experts in joining, cutting and surface treatment of metallic and non-metallic materials by such processes as welding, brazing, soldering, thermal cutting, thermal spraying, adhesive bonding and microjoining. IIW work also embraces allied fields including quality assurance, non-destructive testing, standardization, inspection, health and safety, education, training, qualification, design and fabrication.

More information about this series at <http://www.springer.com/series/13906>

Bertil Jonsson · G. Dobmann
A.F. Hobbacher · M. Kassner
G. Marquis

IIW Guidelines on Weld Quality in Relationship to Fatigue Strength



INTERNATIONAL INSTITUTE OF WELDING
A world of joining experience

 Springer

Bertil Jonsson
Hauler Loader Division
VOLVO Construction Equipment
Braås
Sweden

M. Kassner
ALSTOM Transport Deutschland GmbH
Salzgitter
Germany

G. Dobmann
Fraunhofer—IZFP
Saarbrücken
Germany

G. Marquis
Department of Applied Mechanics
Aalto University
Espoo
Finland

A.F. Hobbacher
University of Applied Sciences
Wilhelmshaven
Germany

ISSN 2365-435X

ISSN 2365-4368 (electronic)

IIW Collection

ISBN 978-3-319-19197-3

ISBN 978-3-319-19198-0 (eBook)

DOI 10.1007/978-3-319-19198-0

Library of Congress Control Number: 2016936442

© International Institute of Welding 2016

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

This Springer imprint is published by Springer Nature

The registered company is Springer International Publishing AG Switzerland

Contents

1	Introduction	1
1.1	Existing IIW Recommendations and Guidelines.	1
1.2	Scope.	2
	References	3
2	Design for Purpose	5
2.1	Limit State Design.	5
2.2	Fatigue Versus Static Loading.	6
2.3	Weld Quality and Design.	7
2.4	Practical Design for Purpose.	9
3	IIW Fatigue Assessment Procedures	11
3.1	Available Assessment Procedures	11
3.1.1	Fatigue Testing.	11
3.1.2	Nominal Stress Method	12
3.1.3	Structural Hot Spot Stress Method.	14
3.1.4	Effective Notch Stress Method	16
3.1.5	Fracture Mechanics Method	17
	References	18
4	Classification of Weld Imperfections and Features	19
4.1	Overview About Classifications of Weld Imperfections in ISO Standards	19
4.2	Classification of Geometric Imperfections for Fusion Welds in Metallic Materials, ISO 6520-1	20
4.3	Quality Criteria of Welded Joints in ISO 5817	23
4.4	The Relationship Between ISO 5817 and Fatigue Strength for Arc-Welded Steel Structures	27
	References	38
5	Weld Quality Levels for Fatigue Loaded Structures	39
5.1	Assessment of Defects	39
5.2	Requirements for a Production Standard Weld Quality	40

5.2.1	Effect of Toe Geometry	40
5.2.2	Effect of Misalignment.	43
5.2.3	Effect of Undercut.	45
5.2.4	Effect of Cold Laps.	49
5.2.5	Effect of Inclusions and Porosity.	51
5.2.6	Effect of Cracks and Crack-Like Imperfections	53
5.3	Design of Experiments (DOE) Using Simulation	57
5.3.1	Parameters Using the Effective Notch Method on Butt Welds	57
5.3.2	Parameters Using the Effective Notch Method on Fillet Welds.	58
5.4	Fatigue Design of High-Quality Welds.	59
5.4.1	Effect of Improvement Methods	59
5.4.2	Improvement of Shape of Weld Toe	60
5.4.3	Improvement by Compressive Residual Stress	61
	References	61
6	Root Side Requirements.	65
6.1	General	65
6.2	Joints with Weld Root as Weakest Point	65
6.3	Designation for Penetration.	65
6.4	Design of Experiments on an Example of Load-Carrying Weld	66
6.5	Throat Size Versus Penetration	69
	References	71
7	Inspection, Quality Control, and Documentation	73
7.1	Probability of Detection (POD) and Probability of Sizing (POS).	75
7.2	Imperfection-Specific and NDT Technique-Specific POD	79
7.3	Human Factor Influences	79
7.4	Real-Time Inspection.	80
7.5	Notes on Limits	81
	References	88
8	Fitness for Service	91
8.1	General	91
8.2	Stress Intensity Factors.	92
8.2.1	General Solution.	92
8.2.2	Stress Intensity Factor for Welds.	92
8.2.3	Weight Function Approach.	93
8.2.4	Finite Element Programs	95
8.2.5	Aspect Ratio.	95
8.2.6	Assessment of Welded Joints Without Detected Imperfections	96

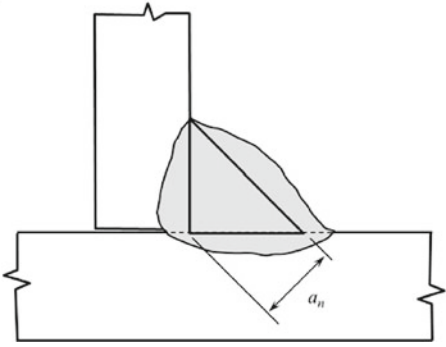
- 8.3 Fatigue Assessment by Crack Propagation 96
- 8.4 Material Parameters for Crack Propagation 98
- 8.5 Dimensions of Cracks 99
- 8.6 Formulae for Stress Intensity Factors 100
 - 8.6.1 Standard Solutions 100
 - 8.6.2 Solutions for Magnification Function M_k 101
 - 8.6.3 Examples of a Fracture Mechanics Assessment 103
- 8.7 Computation of Results Using Design of Experiments Theory. 108
 - 8.7.1 Butt Welded from 1 Side Only, Flexible Boundary
Conditions 109
 - 8.7.2 Butt Welded from 2 Sides, Symmetric Weld 109
 - 8.7.3 Load-Carrying Cruciform Joint 110
 - 8.7.4 Non-load-Carrying Cruciform Joint 112
- References 113

Nomenclature

Cold lap	A region of non-fused overlap between the weld metal and base plate which results in an imperfection parallel to the base plate
Effective notch stress	Elastic notch stress calculated for a notch with a certain assumed notch radius
FAT	All fatigue resistance data including the FAT classes are given as characteristic values, which are assumed to represent a survival probability of at least 95 %, calculated from mean value on the basis of a two-sided 75 % tolerance limits of the mean. Other existing definitions, e.g., a survival probability of 95 % on the basis of 95 % one-sided limit of the mean or means minus two standard deviations corresponding to a survival probability of 97.7 %, are practically equal for engineering applications. Levels are arranged in steps
Geometric stress	See structural stress
Improved welds	Welds for which the weld toe is treated after welding by a grinding, re-melting, or peening operation. IIW Guidelines for select post-weld treatment methods have been published
Inclusion	Non-metallic material entrapped in molten metal during solidification
High quality weld	Welds with a lower level of imperfections such that it has fatigue strength greater than that defined in the IIW Guidelines and Recommendations with respect to nominal stress, hot spot stress, or effective notch stress. The improvement in fatigue strength is normally two FAT classes
Hot spot stress	See structural stress
k_m	Stress magnification factor for misalignment
Micro lack of fusion	Same as cold lap, used in some standards

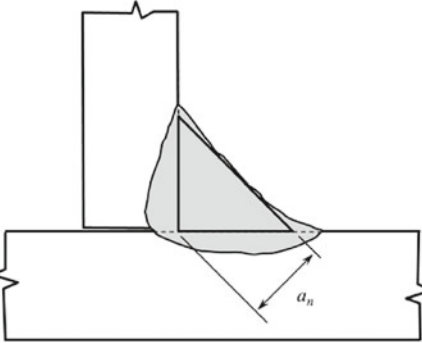
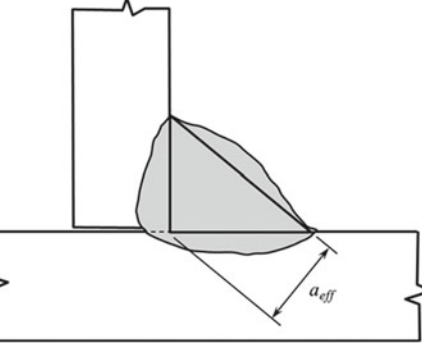
Normal quality weld	Welds for which the level of imperfections is such that it satisfies the fatigue strength requirement defined in the IIW Guidelines and Recommendations with respect to nominal stress, hot spot stress, or effective notch stress
Notch stress	See effective notch stress
Overlap	A protrusion of weld metal beyond the weld toe or weld root. An overlap may be fused or non-fused. A toe overlap without fusion between the weld metal and base plate is the same as a cold lap
Porosity	Porosity is used to describe cavities or pores caused by gas entrapment in molten metal during solidification
N_f	Cycles to failure
Slag inclusion	See inclusion
Structural stress	A stress in a component, resolved to take into account the effects of a structural discontinuity on the surface of a hot spot, consisting of membrane and shell-bending stress components
Undercut	An unfilled groove along the fusion line between weld metal and base plate
ΔS or $\Delta \sigma$	Nominal stress range
ΔS_c or $\Delta \sigma_c$	Characteristic nominal stress range in MPa (see FAT above), but is a continuous variable when FAT are given in steps

Throat Thicknesses

Term	IIW terminology	Figure
Throat thickness	Thickness of a fillet weld	
Design throat thickness	Throat thickness specified by the designer	<i>Note</i> See Fig. 13 in ISO 17659
Nominal throat thickness	Design value of the height of the largest isosceles triangle that can be inscribed in the section of a fillet weld	 <p style="text-align: center;">convex weld profile</p>

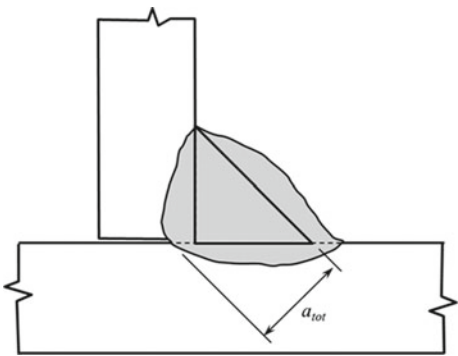
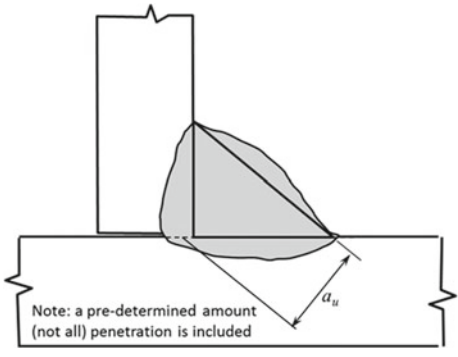
(continued)

(continued)

Term	IIW terminology	Figure
		 <p style="text-align: center;">concave weld profile</p>
Actual throat thickness	Throat thickness of the finalized weld measured according to the design throat thickness	The actual throat thicknesses will depend on whether the nominal throat thickness or effective throat thickness is used in design
Effective throat thickness	Design value of the height of the largest triangle that can be inscribed in the section of a fillet weld	

(continued)

(continued)

Term	IIW terminology	Figure
Maximum throat thickness	Nominal throat thickness to which a maximum amount of fusion penetration is added	 <p>The diagram shows a cross-section of a butt joint with a weld. A vertical line represents the throat thickness. A shaded area represents the fusion penetration. A dashed horizontal line extends from the throat thickness to the penetration. An arrow labeled a_{tot} indicates the total distance from the throat to the tip of the penetration.</p>
Utilized throat thickness	Effective throat thickness to which a certain amount of penetration is added	 <p>The diagram shows a cross-section of a butt joint with a weld. A vertical line represents the throat thickness. A shaded area represents the fusion penetration. A dashed horizontal line extends from the throat to the penetration. An arrow labeled a_u indicates the distance from the throat to a specific point on the penetration. A note at the bottom of the diagram states: "Note: a pre-determined amount (not all) penetration is included".</p>

Note that other definitions may exist, the above-given are according to IIW, Commission VI