# Effect of Side Groove on the Edge Cracks for Reducing Invalid Double Cantilever Beam Tests

API TECHNICAL REPORT 5DCB
FIRST EDITION, NOVEMBER 2025

ERRATA 1, JULY 2026



## Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed. The use of API publications is voluntary. In some cases, third parties or authorities having jurisdiction may choose to incorporate API standards by reference and may mandate compliance.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

Users of this standard should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations to comply with authorities having jurisdiction.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to ensure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the publisher, API Publishing Services, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

*Copyright © 2025 American Petroleum Institute*

## Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

## Contents


Page

1 Scope ..... 1

2 Normative References ..... 2

3 Effect of Side Groove Root ..... 2
3.1 General ..... 2
3.2 Testing Material ..... 2
3.3 Methodology ..... 2
3.4 Results ..... 5

4 Optimization of Side-groove Configuration ..... 22
4.1 General ..... 22
4.2 Testing Material ..... 22
4.3 DCB Test Procedure ..... 23
4.4 DCB Test Results ..... 23

5 Verification using DCB Specimens Machined by a Third Party ..... 26
5.1 General ..... 26
5.2 Verification Methodology ..... 26
5.3 Test Results ..... 28

6 Complementary Verification ..... 33
6.1 General ..... 33
6.2 Configurations of Side Groove ..... 33
6.3 Methodology ..... 33
6.4 Results ..... 35

7 Conclusion ..... 42

Annex A (informative) Fracture Surface Evaluation for Inspection of Edge Cracks ..... 44

Annex B (informative) Fracture Surface Evaluation for Verification using C110 with Heavy Walls ..... 59

Annex C (informative) Effect of U-Shaped Side Grooves for Lower Strength Material (L80) ..... 84

Annex D (informative) Effect of U-Shaped Side Grooves for Mild Sour Conditions for C110 and C125 ..... 91

Annex E (informative) Comparison of Effect of U-Shaped Side Groove Between Company A and Company B ..... 105


Figures


1 Effect of Excessive Stress Concentration at the Bottom of Side Groove ..... 1
2 FEM Model for Near Chevron Notch for DCB Specimen ..... 3
3 DCB Specimen Side Groove Configuration for FEA ..... 4
4 Each Crack Starter Configuration in NACE TM0177-2016 ..... 4
5 Compliance Curve Evaluation by FEA for the Standard V-shaped Groove with R0.25 mm ..... 6
6 Compliance Curve Evaluation by FEA for the U-shaped Groove with R0.65 mm ..... 7
7 Compliance Curve Evaluation by FEA for the U-shaped Groove with R0.80 mm ..... 8
8 Compliance Curve Evaluation by FEA for the U-shaped Groove with R0.95 mm ..... 9
9a Compliance Curve Evaluation by FEA (1 of 2) ..... 10
9b Compliance Curve Evaluation by FEA (2 of 2) ..... 10
10 Through-wall K Distribution ..... 12
11a Effect of Side-groove Configuration on K Value (1 of 2) ..... 13

11b Effect of Side-groove Configuration on K Value (2 of 2) ..... 13
12a Comparison of K Distribution at Crack Length "a"= 31.75 mm (1 of 2) ..... 15
12b Comparison of K Distribution at Crack Length "a"= 31.75 mm (2 of 2) ..... 15
13a Variation of K Distribution at Center of the Groove Width for Direction of Crack Propagation (1 of 2) ..... 17
13b Variation of K Distribution at Center of the Groove Width for Direction of Crack Propagation (2 of 2) ..... 17
14 Variation of K Distribution at Bottom of the Groove for Direction of Crack Propagation ..... 19
15 Comparison of Total Length of Edge Crack ..... 20
16 Comparison of $K_{ISSC}$ Values Obtained from Specimens with Validity of Crack (SSC) Growth ..... 21
17 Comparison of Fracture Surface after DCB Testing ..... 22
18 Comparison of Occurrence of Edge Crack ..... 25
19 Comparison of $K_{ISSC}$ Values ..... 25
20 Optimization of Side Groove Configuration for C110 in 1 bar $H_2S$-saturated NACE Solution A ..... 26
21 Comparison of Edge Crack Width for Test #1 ..... 29
22 Compliance Curve for Test #1 ..... 30
23 Comparison of Edge Crack Width for Test #2 ..... 31
24 Compliance Curve for Test #2 ..... 32
25 Location for EBSD Analysis ..... 33
26 Comparison of KAM at the Base of Each Side Groove ..... 36
27 Comparison of Invalidity Ratio of Testing Results and the Occurrence of Edge Cracks ..... 40
28 Relationship Between $K_{ISSC}$ and HRC Hardness of DCB Test Specimen ..... 40
29 Comparison of Average $K_{ISSC}$ for the Different Side Grooves ..... 41
30 Compliance Curve Evaluation ..... 41
31 Proposal for C110 in 1 bar $H_2S$-saturated NACE Solution A ..... 43
A.1 Proposed Method to Reveal Edge Cracks ..... 44
A.2 Examples of Significant Edge Cracks ..... 45
A.3 Examples of Insignificant Edge Cracks ..... 46
A.4 Company A Equipment Setup ..... 48
A.5 Invalid Test Specimen #292 ..... 48
A.6 Valid Test Specimen #293 ..... 49
A.7 Valid Test Specimen #294 ..... 50
A.8 Invalid Test Specimen #295 ..... 50
A.9 Valid Test Specimen #296 ..... 51
A.10 Valid Test Specimen #332 ..... 52
A.11 Valid Test Specimen #333 ..... 52
A.12 Valid Test Specimen #334 ..... 53
A.13 Valid Test Specimen #335 ..... 54
A.14 Invalid Test Specimen #336 ..... 54
A.15 Valid Test Specimen #347 ..... 55
A.16 Invalid Test Specimen #348 ..... 56
A.17 Valid Test Specimen #349 ..... 56
A.18 Valid Test Specimen #350 ..... 57
A.19 Valid Test Specimen #351 ..... 58
B.1 Test Specimen #QPT1-1 ..... 59
B.2 Test Specimen #QPT1-2 ..... 60

B.3 Test Specimen #QPT1-3 ..... 60
B.4 Test Specimen #QPT1-4 ..... 61
B.5 Test Specimen #QPT1-5 ..... 62
B.6 Test Specimen #QPT1-6 ..... 62
B.7 Test Specimen #QPT1-7 ..... 63
B.8 Test Specimen #QPT1-8 ..... 64
B.9 Test Specimen #QPT1-9 ..... 64
B.10 Test Specimen #QPT1-10 ..... 65
B.11 Test Specimen #QPT1-11 ..... 66
B.12 Test Specimen #QPT1-12 ..... 66
B.13 Test Specimen #QPT2-1 ..... 67
B.14 Test Specimen #QPT2-2 ..... 68
B.15 Test Specimen #QPT2-3 ..... 68
B.16 Test Specimen #QPT2-4 ..... 69
B.17 Test Specimen #QPT2-5 ..... 70
B.18 Test Specimen #QPT2-6 ..... 70
B.19 Test Specimen #QPT2-7 ..... 71
B.20 Test Specimen #QPT2-8 ..... 72
B.21 Test Specimen #QPT2-9 ..... 72
B.22 Test Specimen #QPT2-10 ..... 73
B.23 Test Specimen #QPT2-11 ..... 74
B.24 Test Specimen #QPT2-12 ..... 74
B.25 Test Specimen #QPT3-1 ..... 75
B.26 Test Specimen #QPT3-2 ..... 76
B.27 Test Specimen #QPT3-3 ..... 76
B.28 Test Specimen #QPT3-4 ..... 77
B.29 Test Specimen #QPT3-5 ..... 78
B.30 Test Specimen #QPT3-6 ..... 78
B.31 Test Specimen #QPT3-7 ..... 79
B.32 Test Specimen #QPT3-8 ..... 80
B.33 Test Specimen #QPT3-9 ..... 80
B.34 Test Specimen #QPT3-10 ..... 81
B.35 Test Specimen #QPT3-11 ..... 82
B.36 Test Specimen #QPT3-12 ..... 82
C.1 K Value at Center of the Side Groove ..... 86
C.2 K Value at Bottom of the Side Groove ..... 86
C.3 Results of Compliance Curve Evaluation ..... 88
C.4 Fracture Surface of DCB Specimens with the Standard V-shaped Groove (Mark AT2) ..... 89
C.5 Fracture Surface of DCB Specimens with the U-shaped Groove (Mark AB8) ..... 90
D.1 Comparison of $K_{ISSC}$ for DCB Specimens without Pre-crack for C110 Material ..... 94
D.2 Comparison of $K_{ISSC}$ for DCB Specimens with Pre-crack for C110 Material ..... 94
D.3 Comparison of the Occurrence of Edge Cracks for DCB Specimens without Pre-crack for C110 Material ..... 95
D.4 Comparison of the Occurrence of Edge Cracks for DCB Specimens with Pre-crack for C110 Material ..... 95
D.5 Example of Edge Cracks after Tests on C110 Material ..... 96
D.6 Difference of Crack Length Between Bottom of the Groove and at Center of the Width for DCB Specimens without Pre-crack for C110 Material ..... 97

D.7 Difference of Crack Length Between the Bottom of the Groove and at Center of the Width for Specimens with Pre-crack for C110 Material ..... 98
D.8 Comparison of $K_{ISSC}$ for DCB Specimens Without Pre-crack for C125 Material ..... 100
D.9 Comparison of $K_{ISSC}$ for DCB Specimens With Pre-crack for C125 Material ..... 100
D.10 Comparison of the Occurrence of Edge Crack for DCB Specimens Without Pre-crack for C125 ..... 101
D.11 Comparison of the Occurrence of Edge Crack for DCB Specimens With Pre-crack for C125 ..... 101
D.12 Example of Edge Cracks After Tests for C125 ..... 102
D.13 Difference of Crack Length Between Bottom of the Groove and Center of the Width ..... 103
D.14 Difference of Crack Length Between Bottom of the Groove and Center of the Width ..... 104

Tables

1 Material ..... 2
2 Chemical Composition ..... 2
3 FEA Condition ..... 3
4 DCB Testing Conditions ..... 5
5 Pipe Size and Mechanical Properties ..... 23
6 Chemical Composition ..... 23
7 DCB Test Condition ..... 23
8 Results of DCB Testing ..... 24
9 Pipe Size and Mechanical Properties ..... 27
10 Chemical Composition ..... 27
11 Evaluation Program ..... 27
12 DCB Test Condition ..... 28
13 Shaped Groove Test Results for Test #1a ..... 29
14 Shaped Groove Test Results for Test #2 ..... 31
15 Verification Using DCB Specimens Machined by a Third Party ..... 32
16 Pipe Size and Mechanical Properties ..... 34
17 Chemical Composition ..... 34
18 DCB Testing Condition ..... 35
19 Results of DCB Testing for the V-shaped Groove with R0.25 mm ..... 37
20 Results of DCB Testing for the U-shaped Groove with R0.65 mm ..... 38
21 Results of DCB Testing for the U-shaped Groove with R0.95 mm ..... 39
A.1 NACE Method D Test Data ..... 47
A.2 Invalid Test Specimen #292 ..... 49
A.3 Valid Test Specimen #293 ..... 49
A.4 Valid Test Specimen #294 ..... 50
A.5 Invalid Test Specimen #295 ..... 51
A.6 Valid Test Specimen #296 ..... 51
A.7 Valid Test Specimen #332 ..... 52
A.8 Valid Test Specimen #333 ..... 53
A.9 Valid Test Specimen #334 ..... 53
A.10 Valid Test Specimen #335 ..... 54
A.11 Invalid Test Specimen #336 ..... 55
A.12 Valid Test Specimen #347 ..... 55
A.13 Invalid Test Specimen #348 due to “Short Crack” ..... 56
A.14 Valid Test Specimen #349 ..... 57

A.15 Valid Test Specimen #350 ..... 57
A.16 Valid Test Specimen #351 ..... 58
B.1 Valid Test Specimen #QPT1-1 ..... 59
B.2 Valid Test Specimen #QPT1-2 ..... 60
B.3 Valid Test Specimen #QPT1-3 ..... 61
B.4 Valid Test Specimen #QPT1-4 ..... 61
B.5 Invalid Test Specimen #QPT1-5 ..... 62
B.6 Valid Test Specimen #QPT1-6 ..... 63
B.7 Invalid Test Specimen #QPT1-7 ..... 63
B.8 Valid Test Specimen #QPT1-8 ..... 64
B.9 Valid Test Specimen #QPT1-9 ..... 65
B.10 Invalid Test Specimen #QPT1-10 ..... 65
B.11 Valid Test Specimen #QPT1-11 ..... 66
B.12 Valid Test Specimen #QPT1-12 ..... 67
B.13 Valid Test Specimen #QPT2-1 ..... 67
B.14 Valid Test Specimen #QPT2-2 ..... 68
B.15 Valid Test Specimen #QPT2-3 ..... 69
B.16 Valid Test Specimen #QPT2-4 ..... 69
B.17 Valid Test Specimen #QPT2-5 ..... 70
B.18 Valid Test Specimen #QPT2-6 ..... 71
B.19 Valid Test Specimen #QPT2-7 ..... 71
B.20 Valid Test Specimen #QPT2-8 ..... 72
B. 21 Valid Test Specimen #QPT2-9 ..... 73
B.22 Valid Test Specimen #QPT2-10 ..... 73
B.23 Valid Test Specimen #QPT2-11 ..... 74
B.24 Valid Test Specimen #QPT2-12 ..... 75
B.25 Valid Test Specimen #QPT3-1 ..... 75
B.26 Valid Test Specimen #QPT3-2 ..... 76
B.27 Valid Test Specimen #QPT3-3 ..... 77
B.28 Valid Test Specimen #QPT3-4 ..... 77
B.29 Valid Test Specimen #QPT3-5 ..... 78
B.30 Invalid Test Specimen #QPT3-6 ..... 79
B.31 Valid Test Specimen #QPT3-7 ..... 79
B.32 Valid Test Specimen #QPT3-8 ..... 80
B.33 Valid Test Specimen #QPT3-9 ..... 81
B.34 Valid Test Specimen #QPT3-10 ..... 81
B.35 Valid Test Specimen #QPT3-11 ..... 82
B.36 Valid Test Specimen #QPT3-12 ..... 83
C.1 Pipe Size and Mechanical Properties ..... 84
C.2 Chemical Composition ..... 84
C.3 DCB Test Condition for L80 Material ..... 85
C.4 Results of DCB Tests for L80 Material ..... 87
D.1 Pipe Size and Mechanical Properties ..... 91
D.2 Chemical Compositions ..... 91
D.3 DCB Test Conditions ..... 92
D.4 Results for C110 in the NACE Solution D Condition ..... 93
D.5 Results of DCB Tests for C125 Material ..... 99
E.1 Company A DCB Test Results ..... 105
E.2 Company B DCB Test Results ..... 106

## Introduction

**Background:** For NACE TM0177-2016, Method D (Double Cantilever Beam Test; DCB), it has been pointed out that edge cracks prevent the progress of sulfide stress cracking (SSC) to occur in API 5CT Grade C110, which affects the evaluation. It has been reported that one of the causes is excessive stress concentration at the bottom of the V-shaped groove with root (R) 0.25 mm specified in NACE TM0177, which helps to initiate an edge crack. Optimization of side-groove root configuration was discussed by the API committee.

**Investigation on effect of side groove root:** In terms of $KI$ (stress concentration) distribution at the groove, effectiveness of U-shaped grooves on reducing the edge crack was shown. For Grade C110 in 1 bar $H_2S$-saturated NACE Solution A, there is no significant difference in $K_{ISSC}$ among the standard V-shaped and U-shaped grooves. In addition, it was confirmed that there is no significant difference in compliance between each notch type.

**Optimization of side-groove configuration:** For Grade C110 in 1 bar $H_2S$-saturated NACE Solution A, there are small differences in occurring edge crack among U-shaped grooves with R0.65 mm and R0.95 mm. R0.65 mm is suitable to prevent both edge crack and non-planar.

**Verification using DCB specimens machined by third party:** For Grade C110 in 1 bar $H_2S$-saturated NACE Solution A, the effectiveness of a U-shaped side groove was also verified using specimens machined by a third party.

**Complementary verification:** In terms of inspection of the edge crack, machining effect, and verification for Grade C110 with heavier wall (coupling stock) in 1 bar $H_2S$-saturated NACE Solution A, the effectiveness of U-shaped grooves was confirmed.

**Conclusion:** The inclusion of U-shaped groove with R0.65 mm in NACE TM0177, Method D, as a viable option for Grade C110 to prevent the occurrence of edge crack for the following grade and test condition:

- API 5CT Grade C110;
- 1 bar $H_2S$-saturated NACE TM0177 Solution A, standard size DCB specimen.

For other grades and test environments other than Grade C110 in Solution A, this can be applicable if the effectiveness of U-shaped grooves can be validated and documented.

It was agreed to include the proposed U-shaped side-grooves as an option in NACE TM0177, Method D.

# Effects of Side Groove on the Edge Cracks for Reducing Invalid Double Cantilever Beam Tests

## 1 Scope

**1.1** To help establish the technical basis for accurately using the double cantilever beam (DCB) test, API sponsored research on the methodology of continuous DCB testing. This work established the testing conditions of specimen design, arm displacement, chemical makeup of the aqueous test solution (composition and pH), time, and temperature. This has brought the state of the art to the point where the proper arm displacements can be selected for both NACE standard conditions and for fit-for-purpose conditions, thereby minimizing the number of invalid tests.

**1.2** The rapidly expanding use of C-110 casing in the search for new supplies of oil and gas in sour formations has made it crucial to accurately characterize the resistance of such tubulars to sulfide stress cracking (SSC). This is best done by the DCB test, the only test that gives a numeric value from each specimen (other tests rely on the statistical analysis of fail/no-fail results, a process that does not give such rapid and precise ratings as does the DCB test). For this reason, the DCB test has gained wide acceptance since it was standardized by NACE in 1990.

**1.3** The fracture toughness calculated by NACE TM0177-2016 [1], Method D, is evaluated by cracks that grow vertically with respect to the direction of opening stress due to wedge insertion. As shown in Figure 1, edge cracks that prevent the progress of sulfide stress cracking (SSC) occur in high-strength low-alloy oil country tubular goods such as API 5CT, Grade C110 material (specified minimum yield strength is 760 MP), which affects the evaluation. When the test specimen specified in NACE TM0177-2016 is used, it has been reported that one of the causes is excessive stress concentration at the bottom of the V-shaped side groove with root (R) 0.25 mm, which helps to initiate an edge crack. If edge cracks occur, there is a risk that the results will be judged as invalid by NACE TM0177-2016, which wastes time for testing due to the retest.

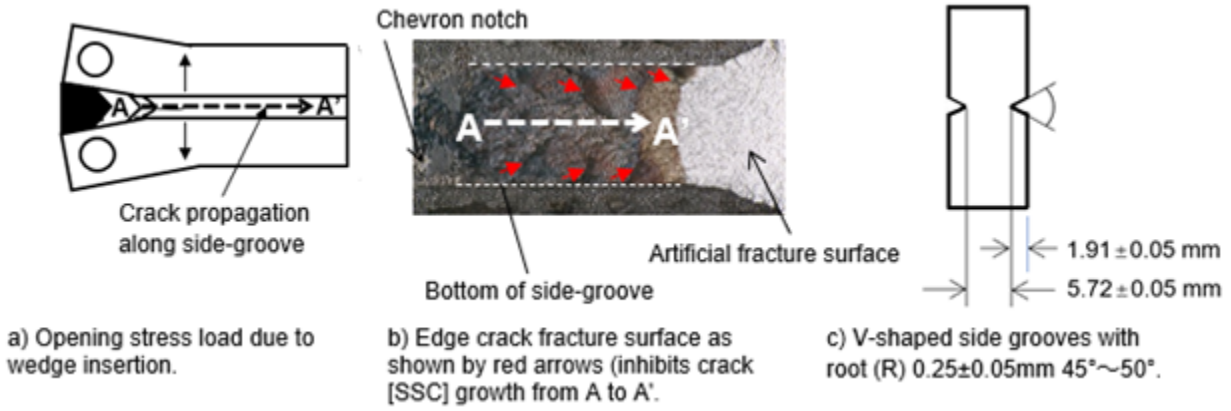



**Figure 1—Effect of Excessive Stress Concentration at the Bottom of Side Groove**