

Duplication is prohibited. 複製禁止



DOI: 10.48708/4756056

HYDROGENIUS DATABASE
— Fatigue Crack-Growth Properties —

No. B58

Database of Long, Fatigue Crack-Growth Properties of
JIS-SCM435 Chromium Molybdenum Steel in 115-MPa-Hydrogen Gas

2015

Research Center for Hydrogen Industrial Use and Storage (HYDROGENIUS)
Kyushu University - JAPAN

Duplication is prohibited. 複製禁止

HYDROGENIUS DATABASE No. B58

Database of Long, Fatigue Crack-Growth Properties of
JIS-SCM435 Chromium Molybdenum Steel in 115-MPa-Hydrogen Gas

Year of publication: 2015

Kyushu University

HYDROGENIUS

Fatigue and Fracture Department

MATSUOKA Saburo (Leader)

MATSUNAGA Hisao

YAMABE Junichiro

HAMADA Shigeru

ITOGA Hisatake

AWANE Tohru

YOSHIKAWA Michio

HYDROGENIUS

SUGIMURA Joichi (Director)

KURIYAMA Nobuhiro (Vice-Director)

Technical Advisory Committee

TAKAKI Setsuo (Chair - Kyushu University)

EGUCHI Tohru (Suzuki Motor Corp.)

HATANO Masaharu (Nippon Steel & Sumikin Stainless Steel Corp.)

HIROTANI Ryuichi (Iwatani Corp.)

IYAMA Akihiro (Nissan Motor Co., Ltd.)

IMAKAWA Kazunari (Nisshin Steel Co., Ltd.)

KANEZAKI Toshihiko (Honda R&D Co., Ltd.)

KAWAMURA Nobuyuki (HAMAI INDUSTRIES LTD.)

KIMURA Kiyoshi (TATSUNO Corp.)

KISHI Kenji (TOKICO TECHNOLOGY LTD.)

KUBOTA Kazumasa (Aichi Steel Corp.)

MAEDA Takashi (JRCM)

MIYAGAWA Kazuo (Honda R&D Co., Ltd.)

MIYAKANE Hirotake (AIR LIQUIDE Japan Ltd.)

NANBA Shigenobu (Kobe Steel, Ltd.)

OHMURA Tomohiko (Nippon Steel & Sumitomo Metal Corp.)

SHINOHARA Mikiya (Nissan Motor Co., Ltd.)

TAKAGI Shusaku (JFE Steel Corp.)

TAKAMI Masayoshi (Toyota Motor Corp.)

TANAKA Hidenori (YAMATO)

WATANABE Osamu (KITZ CORP.)

YAMAGUCHI Norikazu (Taiyo Nippon Sanso Corp.)

YAMAMOTO Hiroshi (Azbil Corp.)

YAMAMOTO Osamu (Toyota Motor Corp.)

YANAGISAWA Yusuke (The Japan Steel Works, Ltd.)

YOSHIKAWA Nobuhiro (University of Tokyo)

YOSHINAGA Tomofumi (Nissan Motor Co., Ltd.)

Users' acceptance of these terms: This HYDROGENIUS DATABASE is available without charge on these express terms that users who view, access, download to use this HYDROGENIUS DATABASE expressly agree to these terms of use indicated herein. If you do not accept these terms, you must not access, view or download to use for any purpose.

Disclaimer: Unless otherwise stated, any products designed and/or fabricated in accordance with this HYDROGENIUS DATABASE are neither endorsed by nor affiliated with HYDROGENIUS. To the extent permitted by laws of Japan, HYDROGENIUS excludes, whether express or implied, all conditions, warranties, representations or other terms which may apply to this HYDROGENIUS DATABASE or any content on it. HYDROGENIUS will not be liable for any direct or indirect losses/damages of any consequence resulting from, whether in contract, tort (including negligence), breach of statutory duty or otherwise whether foreseeable or not, or arising under or in connection with use of or reliance on this HYDROGENIUS DATABASE and any content displayed on this HYDROGENIUS DATABASE, or for inability to use this HYDROGENIUS DATABASE thereon. There are no express or implied warranties of merchantability or fitness for a particular purpose regarding the use of this HYDROGENIUS DATABASE and any content displayed on this HYDROGENIUS DATABASE.

All rights reserved: No part of this HYDROGENIUS DATABASE or any of content displayed on HYDROGENIUS DATABASE may be reproduced or republished in any format, stored in any electronic or alternative retrieval system, or else modified, transferred, distributed, circulated, transmitted or exploited in any manner, without the prior written permission of HYDROGENIUS. All company and product names, design rights and equipment that are featured, used or cited in this HYDROGENIUS DATABASE shall remain any of intellectual property and/or registered trademarks of their respective companies/owners.

Termination: HYDROGENIUS reserves the rights to modify this HYDROGENIUS DATABASE in any way or discontinue providing any or all of this HYDROGENIUS DATABASE without notice.

Duplication is prohibited. 複製禁止

HYDROGENIUS may require the termination of any and all display distribution or other use of any or all of this HYDROGENIUS DATABASE for any reason.

These terms of use, its subject matter and formation are governed by the laws of Japan, and the courts of Japan will have exclusive jurisdiction in case of dispute or claims related to this HYDROGENIUS DATABASE.

Any personal information or data collected from your access to this HYDROGENIUS DATABASE will be handled according to the policy of Kyushu University Institution Repository (QIR) and Privacy Policy of Kyushu University which can be found at <https://www.kyushu-u.ac.jp/en/website/privacypolicy>.

Copyright © 2021

Kyushu University, Research Center for Hydrogen Industrial Use and Storage (HYDROGENIUS)

744 Motoooka, Nishi-ku, Fukuoka-city, Fukuoka, 819-0395, JAPAN

Tel.: +81-92-802-3921 Fax: +81-92-802-3928

E-mail: db@hydrogenius.kyushu-u.ac.jp

Database of Long, Fatigue Crack-Growth Properties of JIS-SCM435 Chromium Molybdenum Steel in 115-MPa-Hydrogen Gas

1. MATERIALS

Table 1. Details of processing and related data for SCM435.

| Heat | Production Process | Product Format | Dimensions (mm) |
|-----------------|--------------------|----------------|---|
| J ¹⁾ | Hot-rolled | Plate | Length: 280 mm Width: 110 mm Thickness: 25 mm |
| K ¹⁾ | Hot-forged | Cylinder | Length: 3800 mm Outer diameter: 357 mm Inner diameter: 306.6 mm Thickness: 25.2 mm |
| T ¹⁾ | Hot-forged | Cylinder | Length: 7530 mm Outer diameter: 270 mm Inner diameter: 210 mm Thickness: 30 mm |

¹⁾ As reported by the manufacturer.

Table 2. Chemical composition of SCM435.

| | Heat | Element (mass%) | | | | | | |
|---------------------|----------------------------|-----------------|------|------|-------|-------|-------|------|
| | | C | Si | Mn | P | S | Cr | Mo |
| Product Analysis | J ¹⁾ | 0.36 | 0.18 | 0.78 | 0.013 | 0.005 | 1.04 | 0.20 |
| | K ²⁾ | 0.37 | 0.22 | 0.84 | 0.012 | 0.005 | 1.15 | 0.24 |
| | T ²⁾ | 0.37 | 0.21 | 0.77 | 0.012 | 0.007 | 1.07 | 0.28 |
| Ladle Analysis | J ³⁾ | 0.34 | 0.19 | 0.76 | 0.014 | 0.005 | 1.06 | 0.20 |
| | J ³⁾ | 0.33 | 0.21 | 0.74 | 0.014 | 0.004 | 1.05 | 0.20 |
| | Requirements ⁴⁾ | Max. | 0.38 | 0.35 | 0.85 | 0.030 | 0.030 | 1.20 |
| Min. | | 0.33 | 0.15 | 0.60 | | | 0.90 | 0.15 |

¹⁾ As recorded by JPEC.

²⁾ As conducted by HYDROGENIUS.

³⁾ As reported by the manufacturer.

⁴⁾ As per JIS G 3441:2012, "Alloy steel tubes for machine purposes" and JIS G 4053:2008, "Low-alloyed steels for machine structural use".

Table 3. Heat-treatment conditions of SCM435.

| Material | Heat | Shape | Quenching | Tempering |
|----------------------|-----------------|--|--------------------------------|-----------------------------|
| Large-sized specimen | J ¹⁾ | Plate | 900°C/60 min, Oil-quenching | 600°C/100 min, Air-cooling |
| | K ¹⁾ | Cylinder | 860°C, Water-spraying | 630°C, Air-cooling |
| | T ¹⁾ | Cylinder | 900°C, Oil-quenching | 560°C, Air-cooling |
| Small-sized specimen | K ²⁾ | Near net shape of specimen ³⁾ | 860°C/60 min, Oil-quenching | 650°C/90 min, Water-cooling |
| | T ²⁾ | Near net shape of specimen ³⁾ | 855°C/30 min, Oil-quenching | 550°C/60 min, Water-cooling |
| | | | | 600°C/60 min, Water-cooling |
| | | | | 650°C/60 min, Water-cooling |

¹⁾ As reported by the manufacturer.

²⁾ As performed by HYDROGENIUS.

³⁾ See Table 5.

2. MECHANICAL PROPERTIES

Table 4. Mechanical properties of SCM435.

| Material | Heat | Shape | Tempering Temperature (°C) | Tensile Properties | | | | Vickers Hardness (HV) |
|----------------------------|-----------------|---------------------------------------|----------------------------|---|------------------------------------|---------------------------------------|---|-----------------------|
| | | | | 0.2% Proof Stress, $\sigma_{0.2}$ (MPa) | Tensile Strength, σ_B (MPa) | Fracture Elongation, ϵ_f (%) | Reduction of Area, ϕ (%) | |
| Large-sized specimen | J ¹⁾ | Plate | 600 | 681 ³⁾ (687) ⁴⁾ | 838 | 23 | 73 | 258 |
| | K ¹⁾ | Cylinder | 630 | 687 ^{3), 5)} (688) ⁴⁾ | 824 ⁵⁾ | 20 ⁵⁾ | 71 ⁵⁾ | 256 ⁵⁾ |
| | | | | 679 ^{3), 5)} (678) ⁴⁾ | 815 ⁵⁾ | 24 ⁵⁾ | 73 ⁵⁾ | |
| | T ¹⁾ | Cylinder | 560 | 785 ^{3), 5)} (788) ⁴⁾ | 951 ⁵⁾ | 17 ⁵⁾ | 65 ⁵⁾ | 289 ⁵⁾ |
| | | | | 779 ^{3), 5)} (778) ⁴⁾ | 943 ⁵⁾ | 17 ⁵⁾ | 66 ⁵⁾ | |
| | | | | 777 ^{3), 5)} (776) ⁴⁾ | 936 ⁵⁾ | 18 ⁵⁾ | 65 ⁵⁾ | |
| Small-sized specimen | K ¹⁾ | Near net shape of specimen | 650 | 800 ³⁾ (802) ⁴⁾ | 903 | 20 | 70 | 284 |
| | | | | T ¹⁾ | Near net shape of specimen | 550 | 1044 ³⁾ (1054) ⁴⁾ | |
| | 600 | 911 ³⁾ (918) ⁴⁾ | 1002 | | | 21 | 68 | 319 |
| | 650 | 772 ³⁾ (775) ⁴⁾ | 875 | | | 24 | 72 | 276 |
| Requirements ²⁾ | | | Max. | | | | | |
| | | | Min. | 785 | 930 | 15 | 50 | |

¹⁾ As performed by HYDROGENIUS.

²⁾ As per JIS G 3441:2012, "Alloy steel tubes for machine purposes" and JIS G 4053:2008, "Low-alloyed steels for machine structural use".

³⁾ As determined by the σ - ϵ curve.

⁴⁾ As determined by the σ -stroke curve. See Fig. A1-6.

⁵⁾ As reproduced from HYDROGENIUS DATABASE Nos. 4 and 6 (Table 10, uncharged L-specimen).

3. FATIGUE CRACK-GROWTH PROPERTIES

Table 5. Fatigue crack-growth test conditions.

| | |
|---|---|
| Testing machines | <ul style="list-style-type: none"> • 100 kN, servo-hydraulic fatigue-machine, in gaseous hydrogen and nitrogen up to 120-MPa • 30 kN, servo-hydraulic fatigue-machine, in air |
| Loading condition | Sinusoidal |
| Environment | <ul style="list-style-type: none"> • 10 ~ 115-MPa-hydrogen gas, at RT • Laboratory air, at RT |
| Gas purity | Hydrogen gas: 99.999% (5 N) |
| Frequency | 0.001 ~ 20 Hz |
| Specimens ^{1), 2)} (dimensions in mm) | |

(Table continues on the following page)

Table 5. Fatigue crack-growth test conditions. (Continued)

| | |
|--|---|
| <p>ΔK conditions²⁾</p> | <p style="text-align: center;">ΔK-constant or ΔP-constant ΔK-increasing</p> $\Delta K = \frac{\Delta P}{B\sqrt{W}} \frac{(2+a)}{(1-a)^{3/2}} (0.886 + 4.64a - 13.32a^2 + 14.72a^3 - 5.6a^4) \quad (1)$ <p style="text-align: right;"> ΔP: Force range W: Width B: Thickness a: Crack size $\alpha = a/W$ </p> |
| <p>Crack-length measurement²⁾</p> | <p style="text-align: center;">Compliance method with clip-on gage</p> $a = W \left(C_0 + C_1 u_x + C_2 u_x^2 + C_3 u_x^3 + C_4 u_x^4 + C_5 u_x^5 \right) \quad (2)$ $u_x = \left\{ \left[\frac{EvB}{P} \right]^{\frac{1}{2}} + 1 \right\}^{-1} \quad (3)$ <p style="text-align: right;"> W: Width E: Elastic modulus v: Displacement between measurement points B: Thickness P: Force $C_0 = 1.0010$ $C_1 = -4.6695$ $C_2 = 18.460$ $C_3 = -236.82$ $C_4 = 1214.9$ $C_5 = -2143.6$ </p> |

¹⁾ The specimen surface was finished by buffing, using a colloidal SiO₂ (0.04 μm) solution.

²⁾ According to ASTM E647 - 08e1, "Standard test method for measurement of fatigue crack growth rates".