Univ. of Waterloo Crack Propagation da/dN Curve Collection for Steels

by
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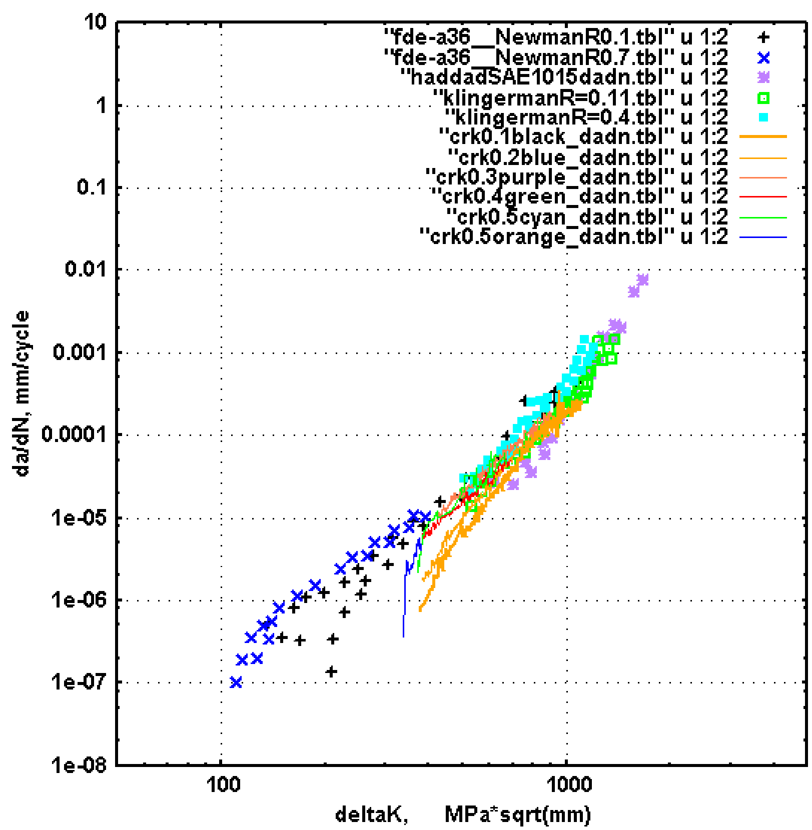
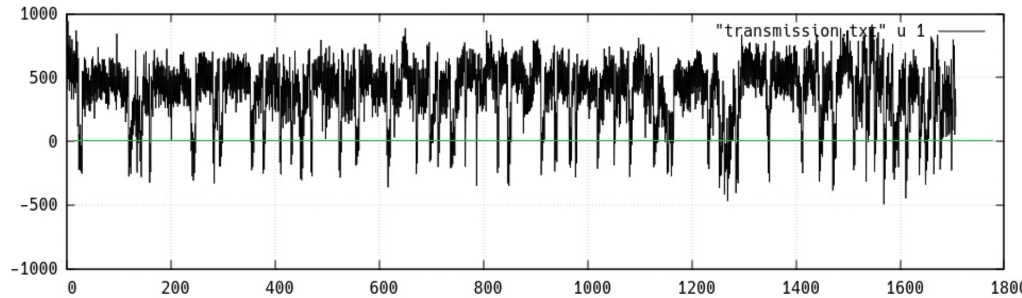
Presented at F.D.E. Comm. of SAE Spring Meeting,
April 15 2020





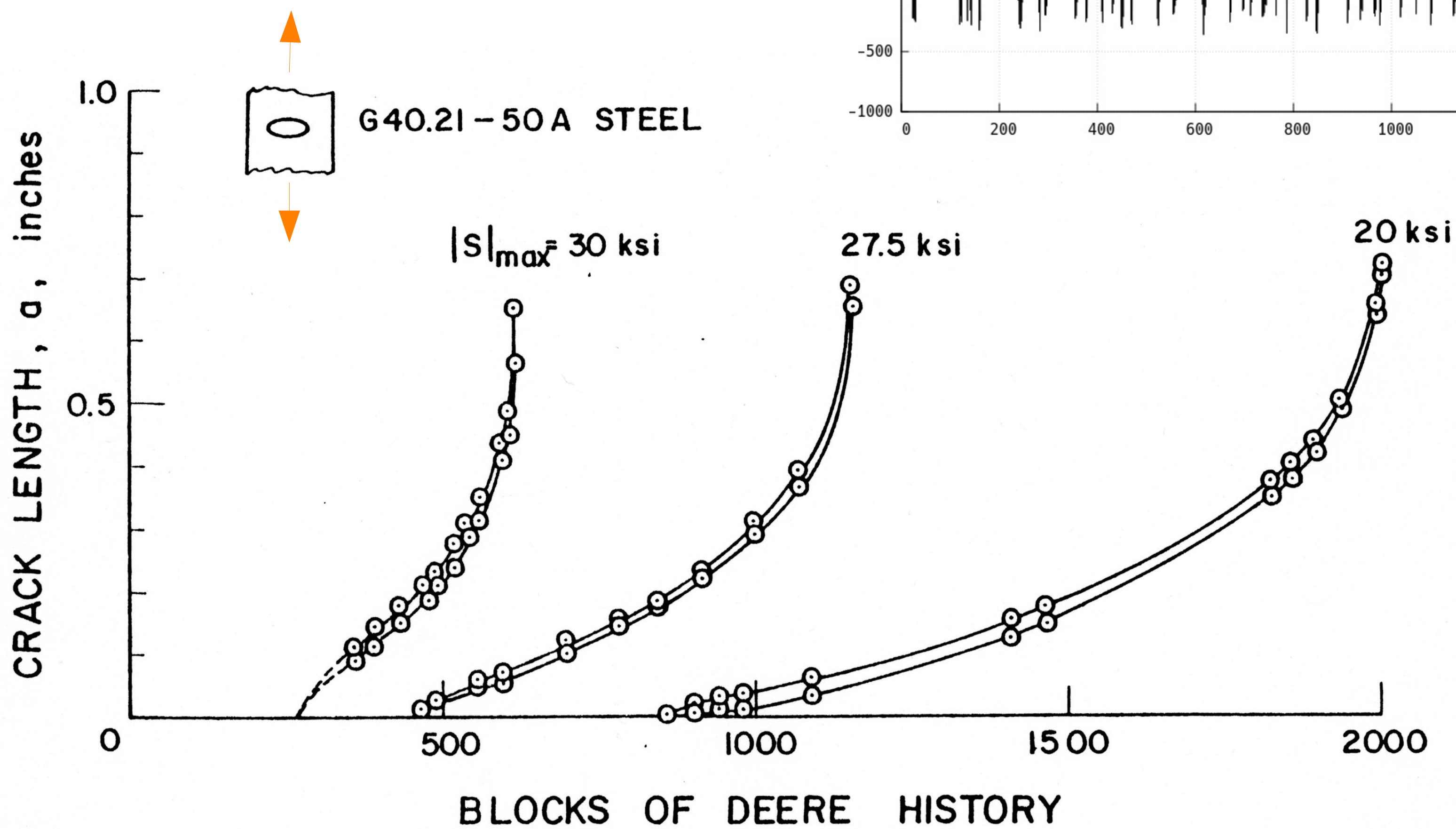
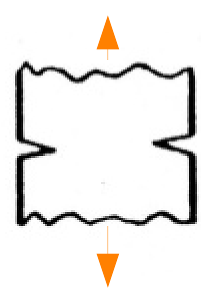


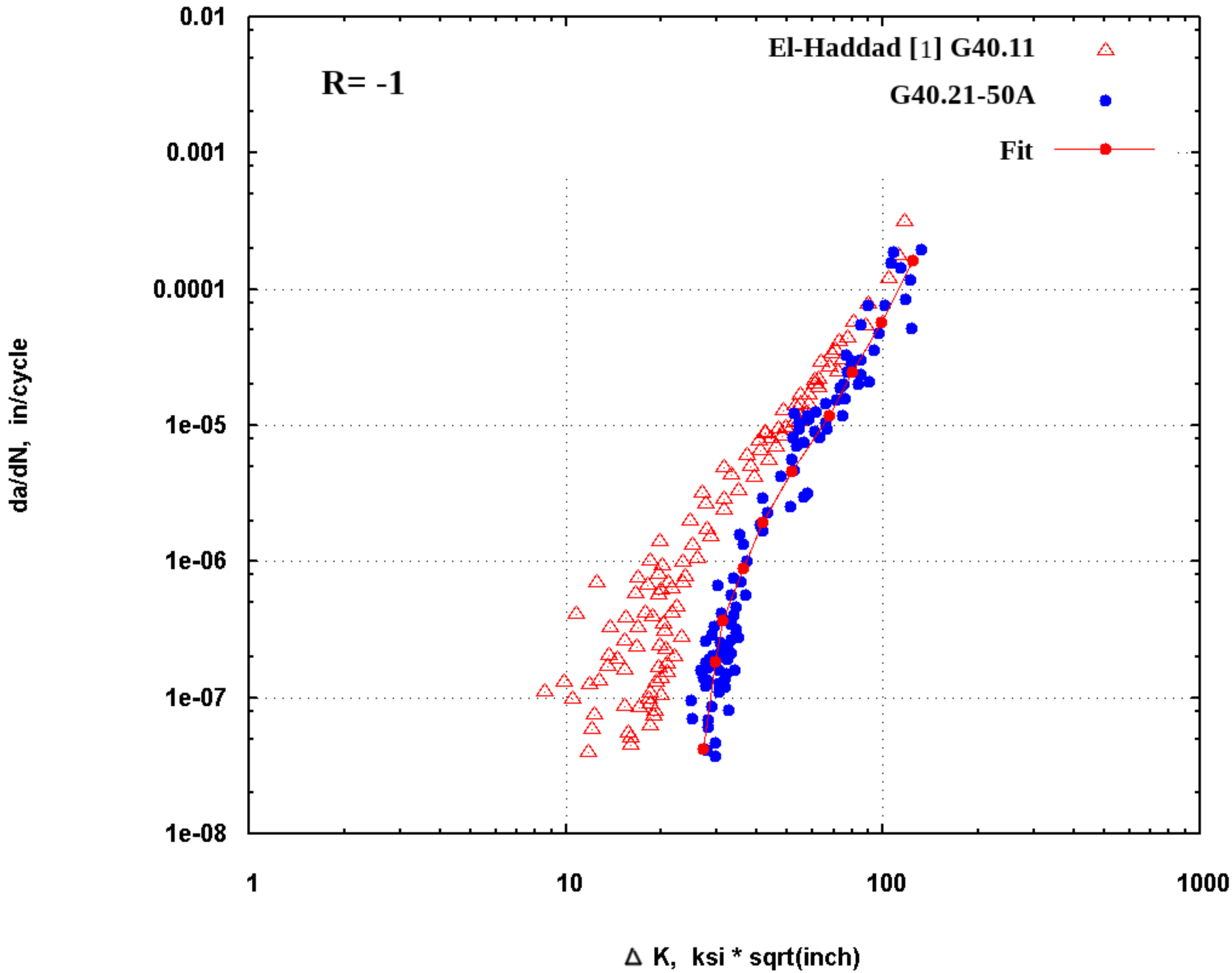
Fig. 56 Observed Crack Propagation Behaviour During Deere Loading History Fatigue (Central Notched Plate, K_t=4.6) F.A.Conle PhD thesis

FCP test specimen →

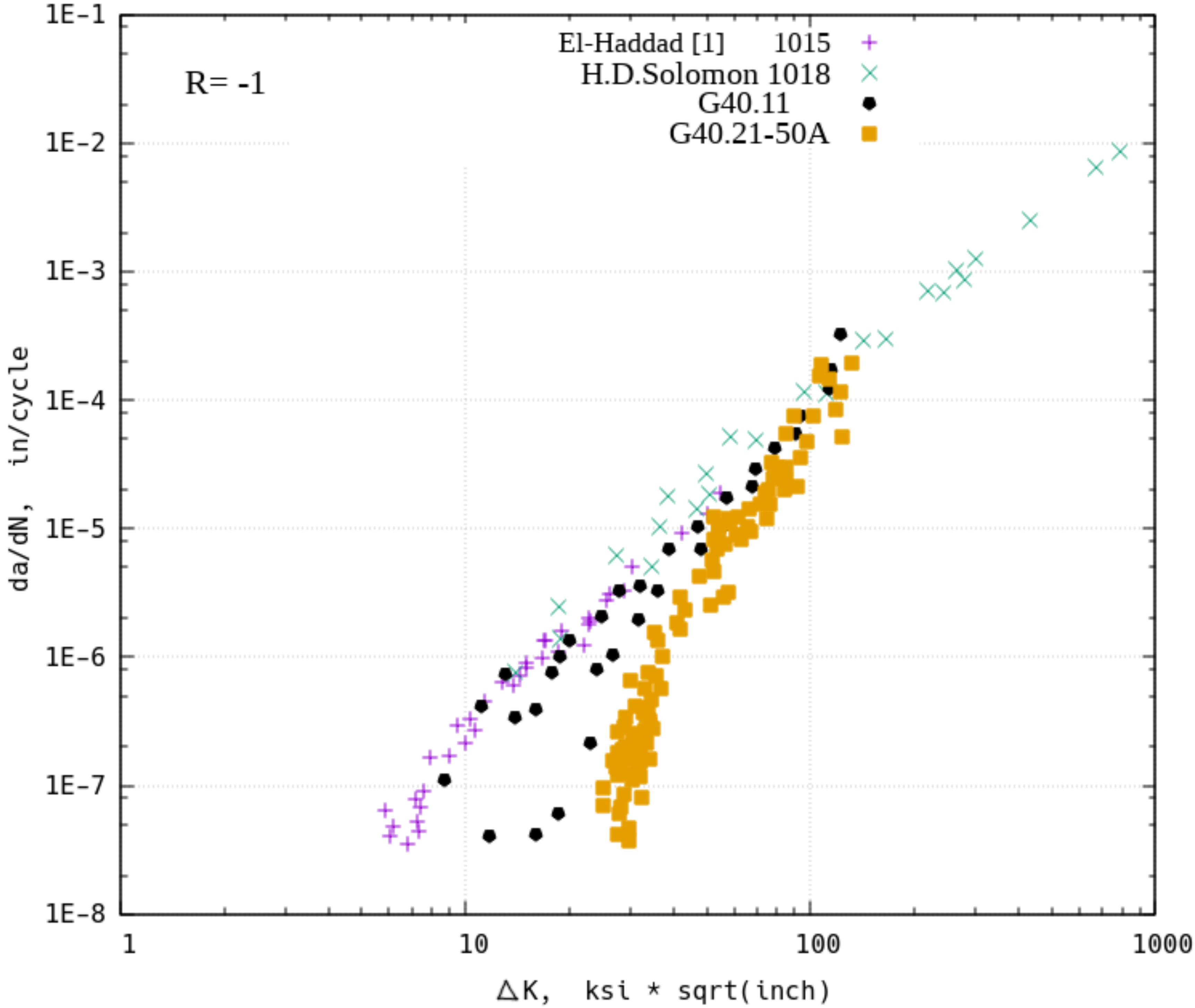


G40.21–50A STEEL

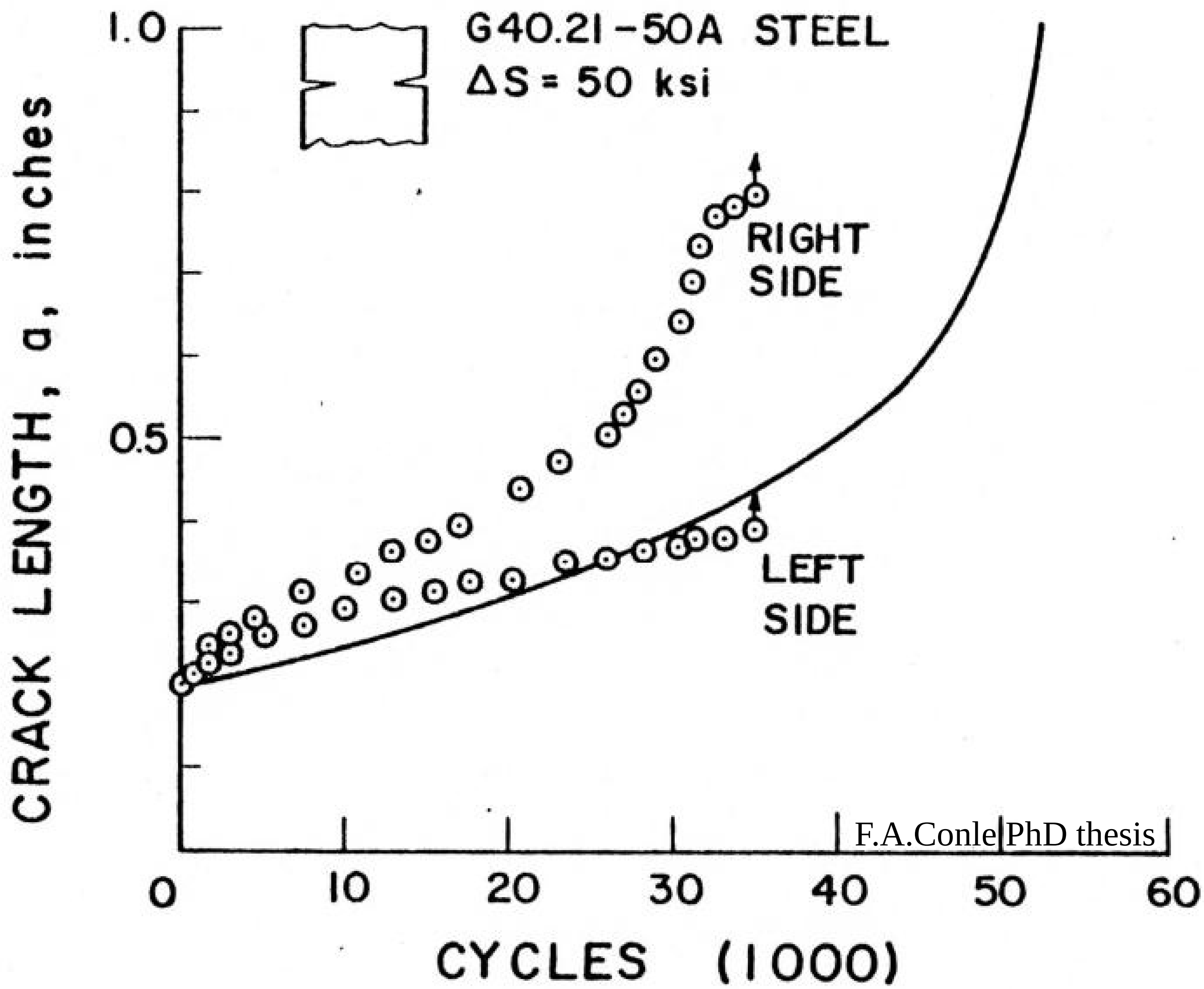
ΔS =40 ksi CA R= -1



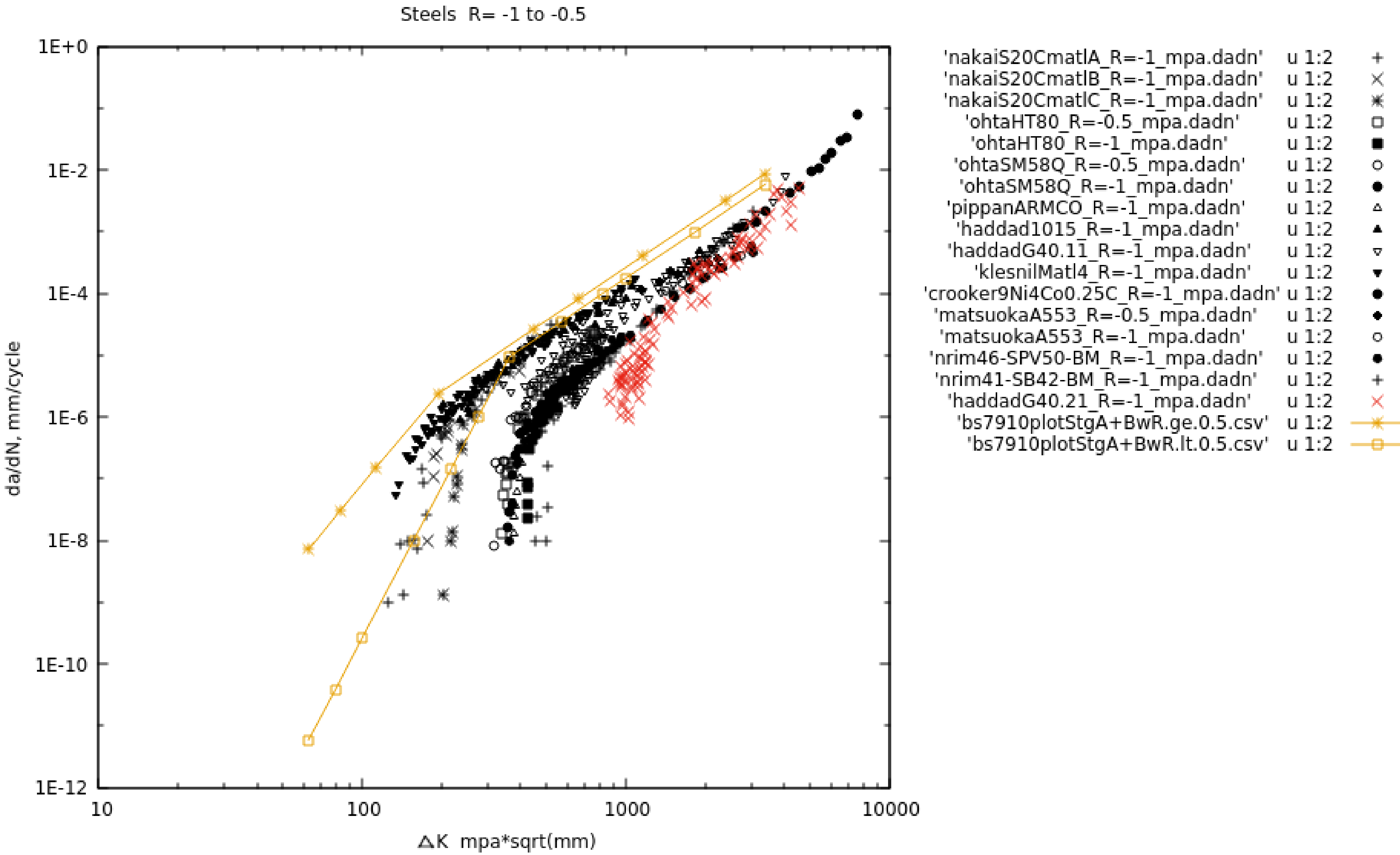
R= -1
El-Haddad [1] G40.11
G40.21-50A
Fit
0.01
0.001
0.0001
1e-05
1e-06
1e-07
1e-08
da/dN, in/cycle
1
10
100
1000
Δ K, ksi * sqrt(inch)

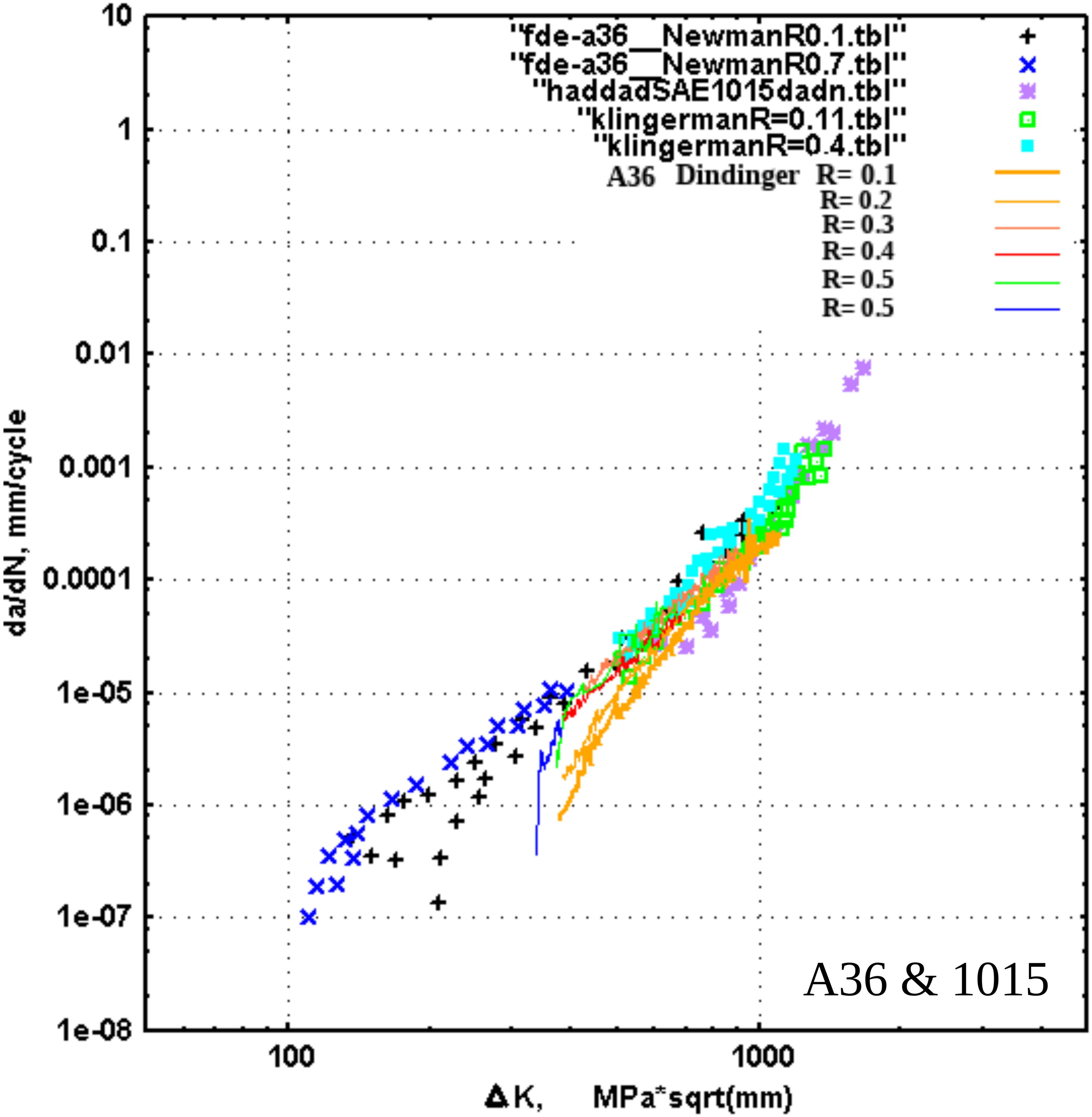


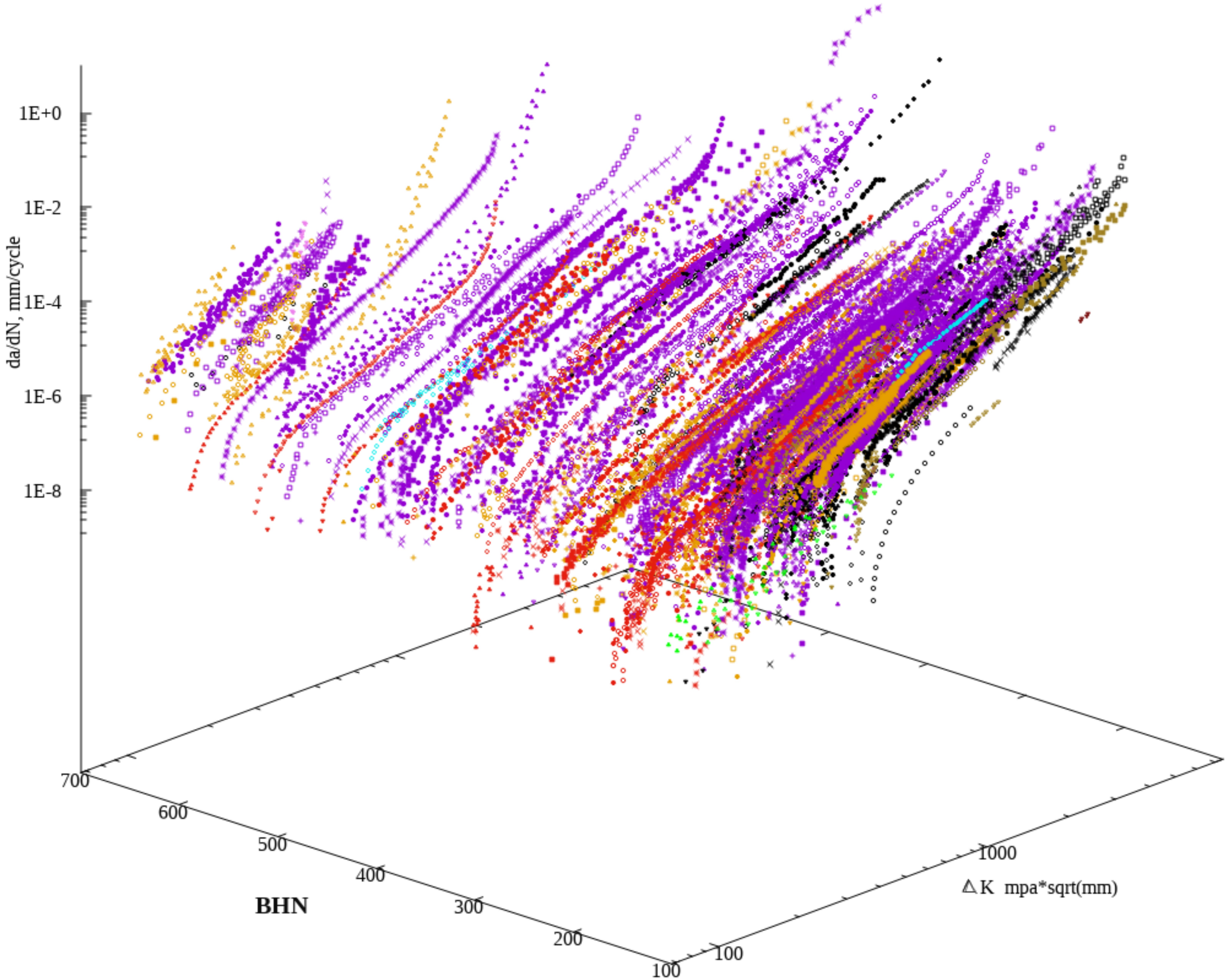
R= -1
El-Haddad [1] 1015
H.D.Solomon 1018
G40.11
G40.21-50A
1E-1
1E-2
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
da/dN, in/cycle
1
10
100
1000
ΔK, ksi * sqrt(inch)



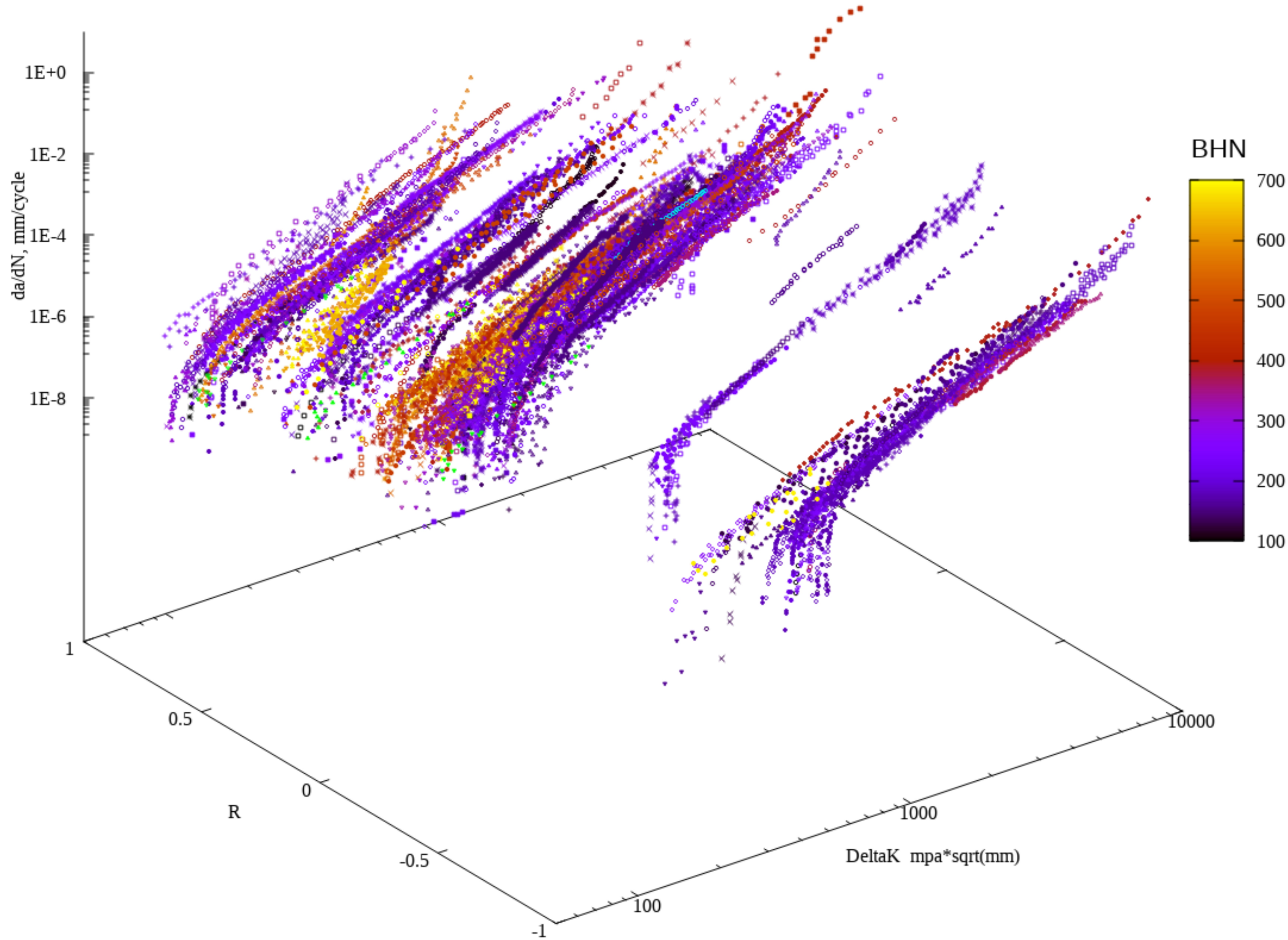
F.A.Conle PhD thesis


Steels R= -1 to -0.5
1E+0
1E-2
1E-4
1E-6
1E-8
1E-10
1E-12
10
100
1000
10000
da/dN, mm/cycle
ΔK mpa*sqrt(mm)
'nakaiS20CmatlA_R=-1_mpa.dadn' u 1:2
'nakaiS20CmatlB_R=-1_mpa.dadn' u 1:2
'nakaiS20CmatlC_R=-1_mpa.dadn' u 1:2
'ohtaHT80_R=-0.5_mpa.dadn' u 1:2
'ohtaHT80_R=-1_mpa.dadn' u 1:2
'ohtaSM58Q_R=-0.5_mpa.dadn' u 1:2
'ohtaSM58Q_R=-1_mpa.dadn' u 1:2
'pippanARMCO_R=-1_mpa.dadn' u 1:2
'haddad1015_R=-1_mpa.dadn' u 1:2
'haddadG40.11_R=-1_mpa.dadn' u 1:2
'klesnilMatl4_R=-1_mpa.dadn' u 1:2
'crooker9Ni4Co0.25C_R=-1_mpa.dadn' u 1:2
'matsuokaA553_R=-0.5_mpa.dadn' u 1:2
'matsuokaA553_R=-1_mpa.dadn' u 1:2
'nrim46-SPV50-BM_R=-1_mpa.dadn' u 1:2
'nrim41-SB42-BM_R=-1_mpa.dadn' u 1:2
'haddadG40.21_R=-1_mpa.dadn' u 1:2
'bs7910plotStgA+BwR.ge.0.5.csv' u 1:2
'bs7910plotStgA+BwR.lt.0.5.csv' u 1:2

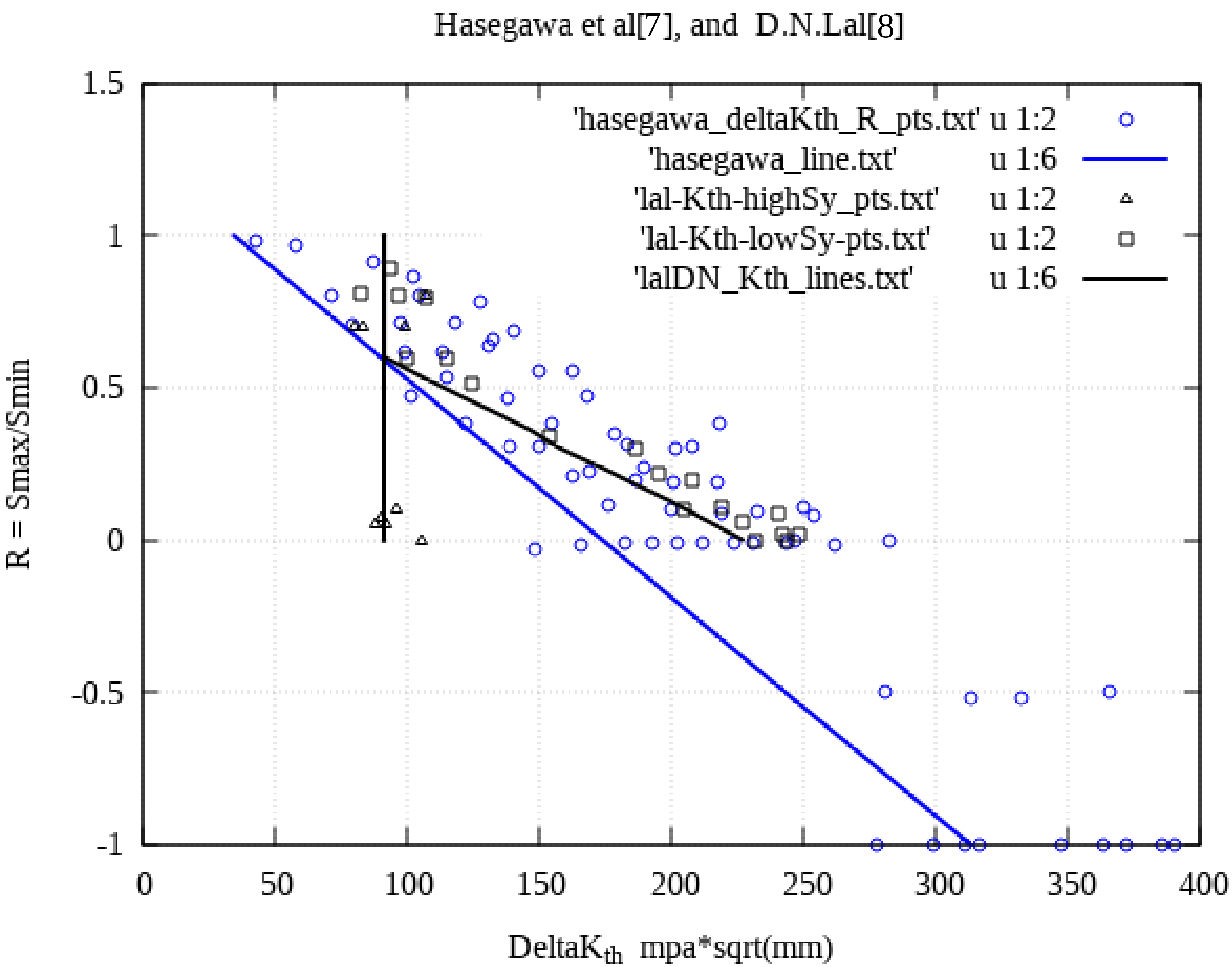

"fde-a36__NewmanR0.1.tbl"
"fde-a36__NewmanR0.7.tbl"
"haddadSAE1015dadn.tbl"
"klingermanR=0.11.tbl"
"klingermanR=0.4.tbl"
A36 Dindinger R= 0.1
R= 0.2
R= 0.3
R= 0.4
R= 0.5
R= 0.5
da/dN, mm/cycle
ΔK, MPa*sqrt(mm)
A36 & 1015



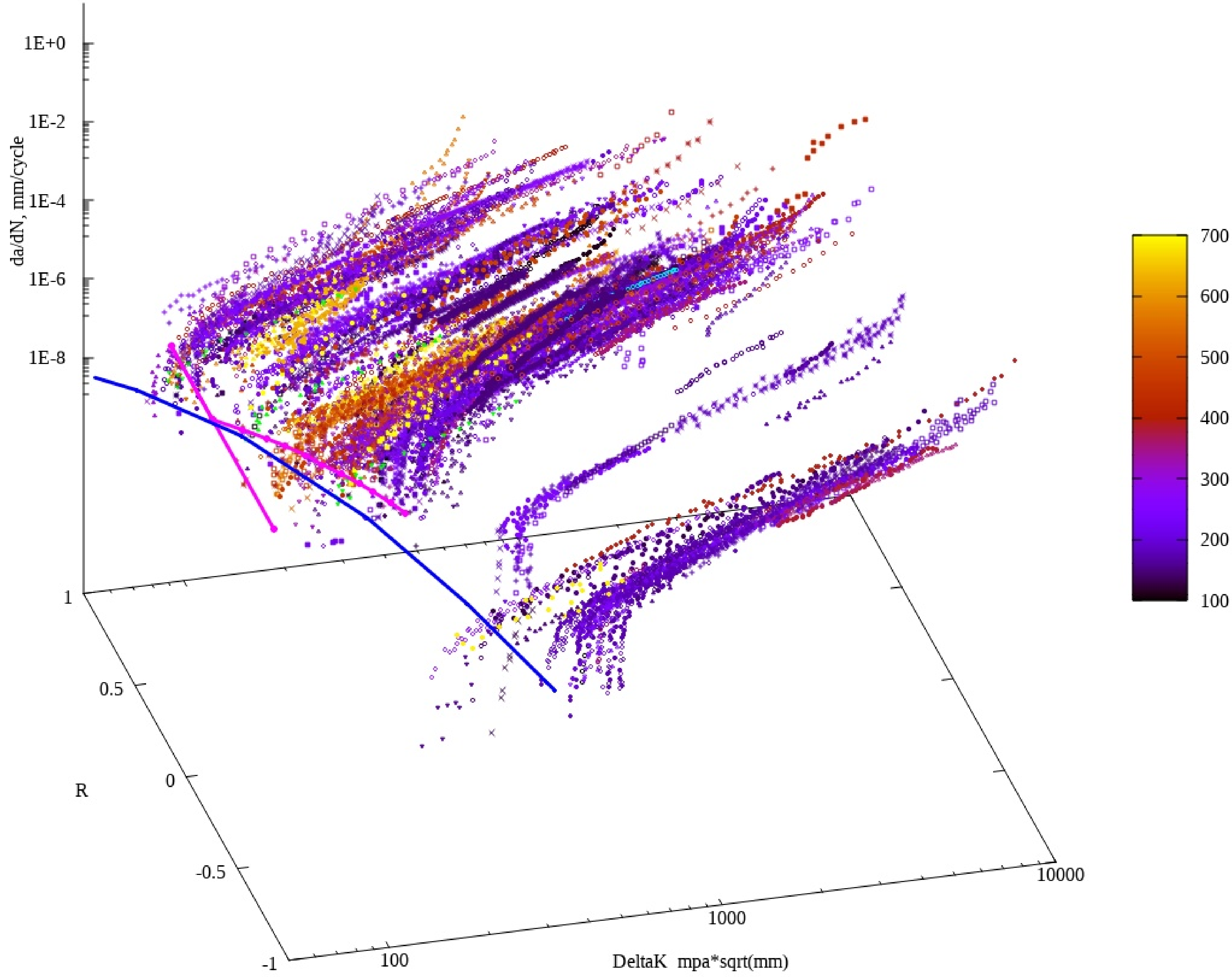
1E+0
1E-2
1E-4
1E-6
1E-8
da/dN, mm/cycle
700
600
500
400
300
200
100
BHN
100
1000
△K mpa*sqrt(mm)

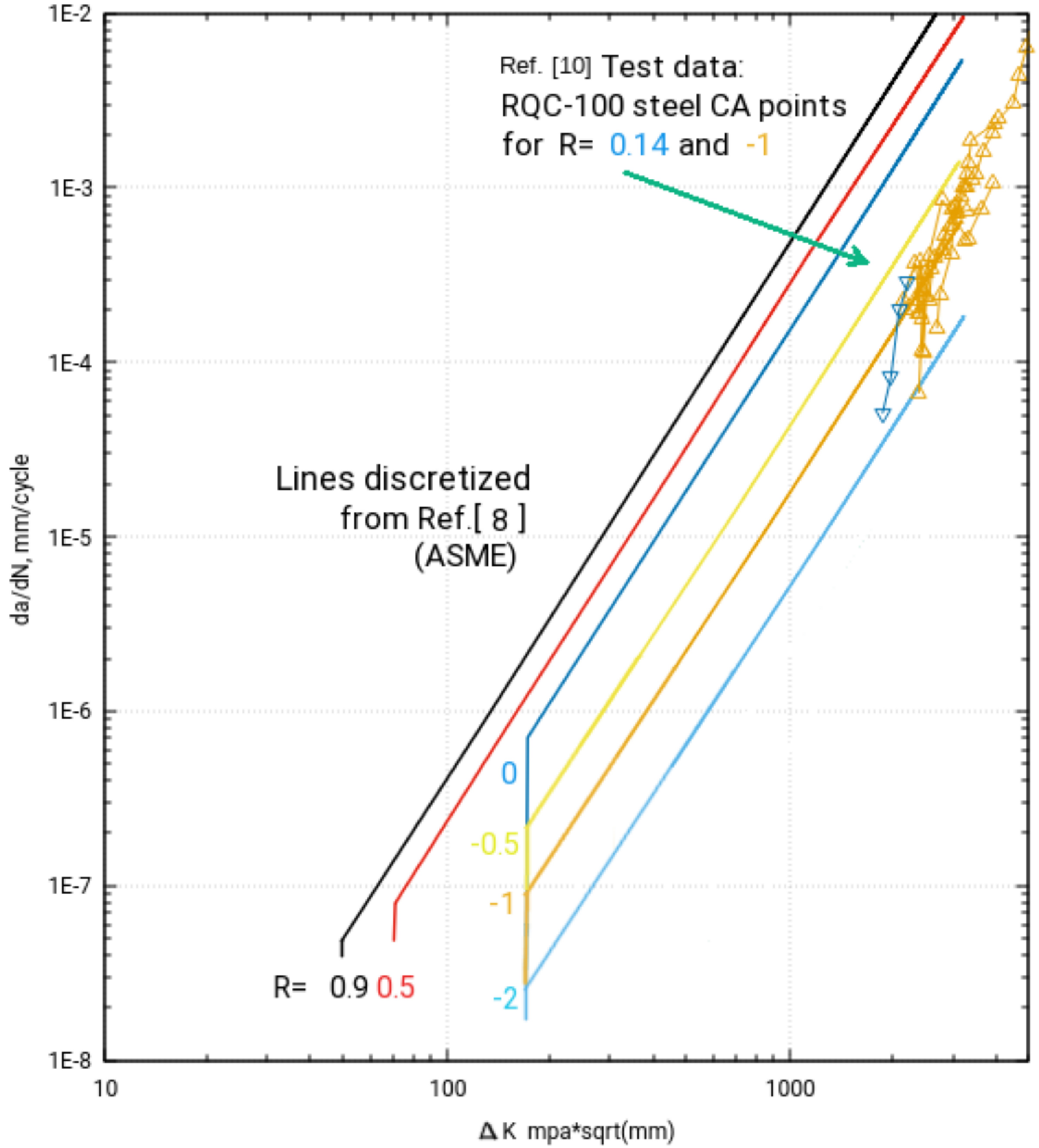


1E+0
1E-2
1E-4
1E-6
1E-8
da/dN, mm/cycle
1
0.5
0
-0.5
-1
R
100
1000
10000
DeltaK mpa*sqrt(mm)
BHN
700
600
500
400
300
200
100

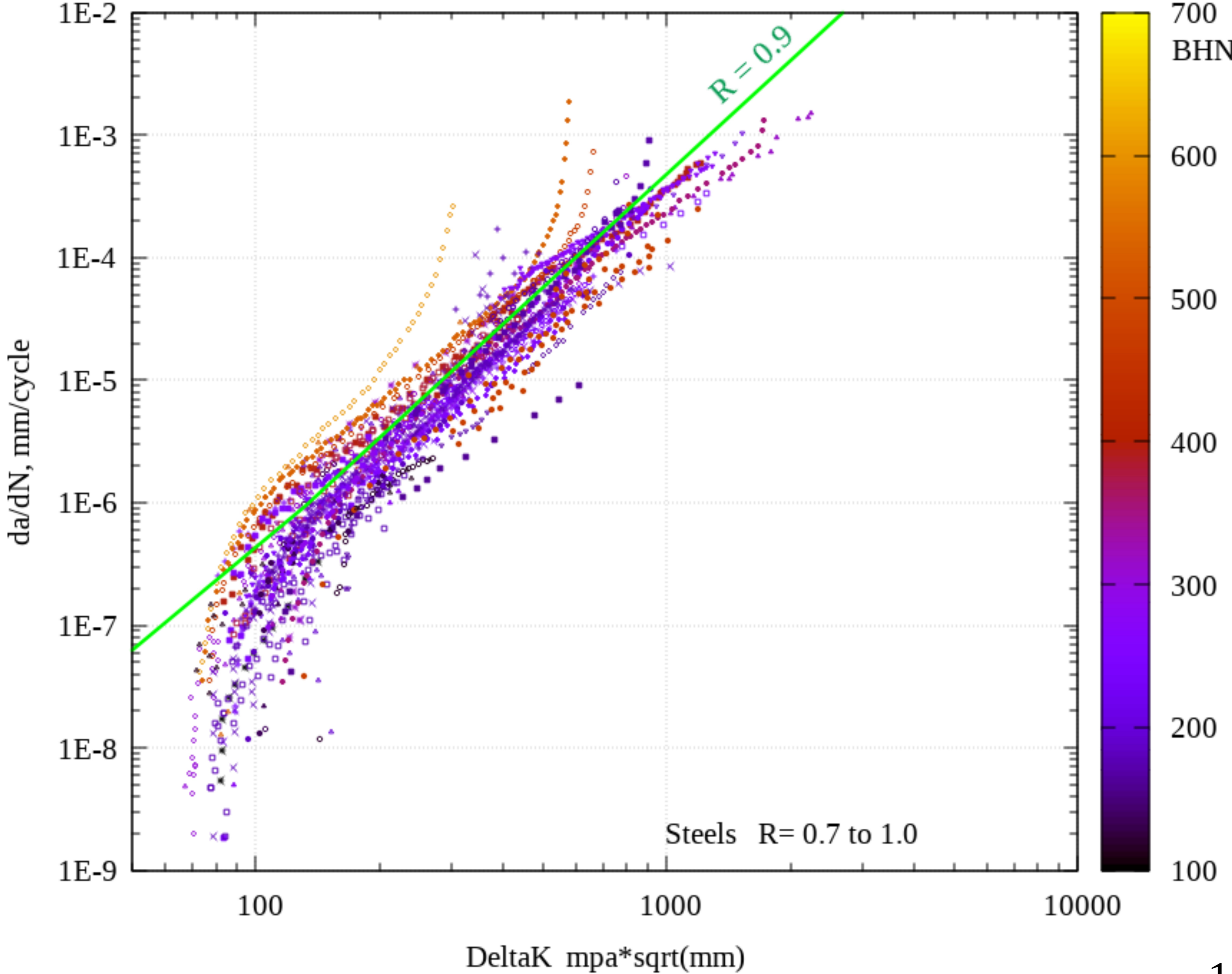


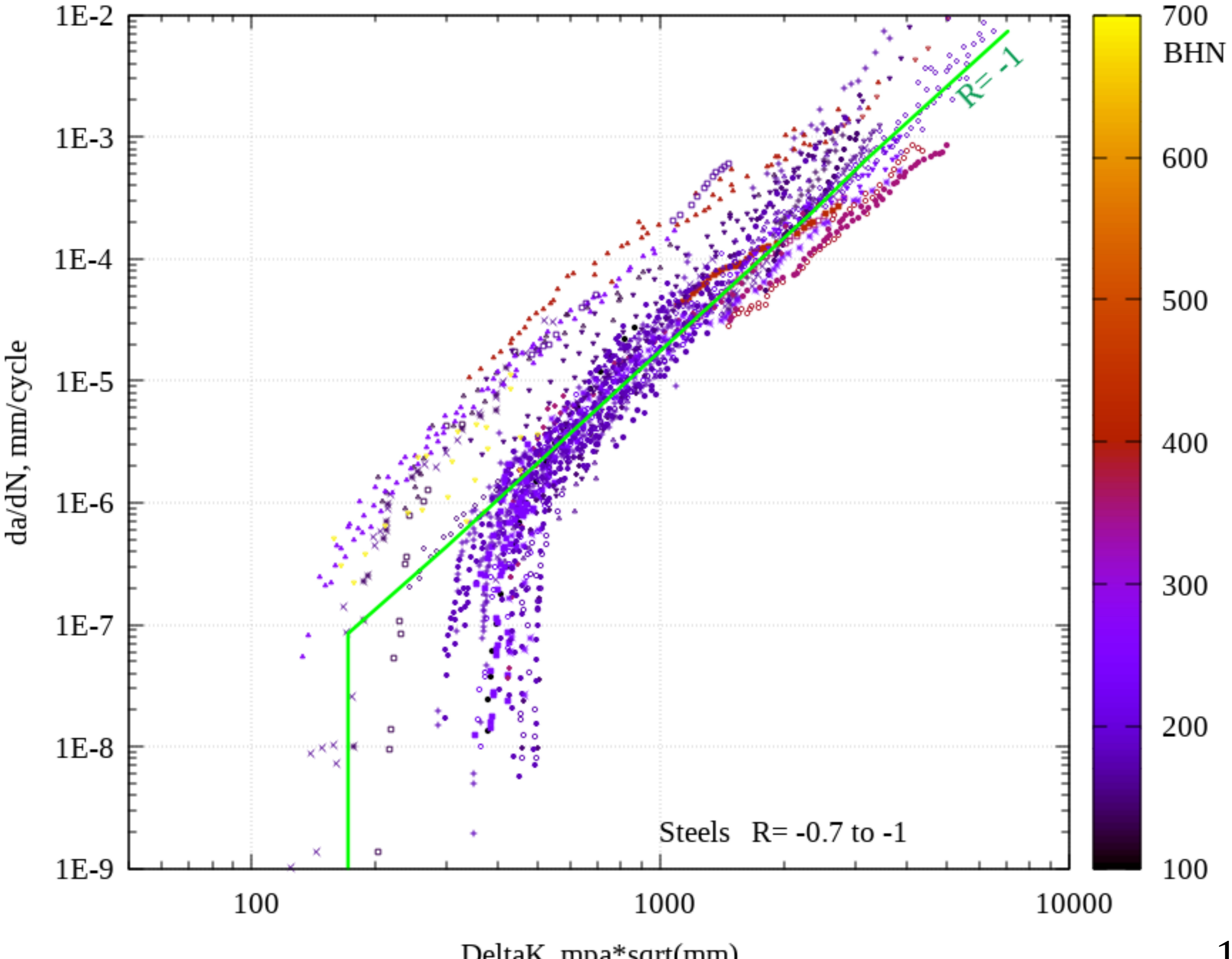
Hasegawa et al[7], and D.N.Lal[8]
'hasegawa_deltaKth_R_pts.txt' u 1:2
'hasegawa_line.txt' u 1:6
'lal-Kth-highSy_pts.txt' u 1:2
'lal-Kth-lowSy-pts.txt' u 1:2
'lalDN_Kth_lines.txt' u 1:6
R = Smax/Smin
DeltaKth mpa*sqrt(mm)
1.5
1
0.5
0
-0.5
-1
0
50
100
150
200
250
300
350
400


1E+0
1E-2
1E-4
1E-6
1E-8
da/dN, mm/cycle
1
0.5
0
-0.5
-1
R
100
1000
10000
DeltaK mpa*sqrt(mm)
700
600
500
400
300
200
100



Ref. [10] Test data:
RQC-100 steel CA points
for R= 0.14 and -1
Lines discretized
from Ref.[8]
(ASME)
0
-0.5
-1
-2
R= 0.9 0.5
1E-2
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
10
100
1000
da/dN, mm/cycle
Δ K mpa*sqrt(mm)


R = 0.9
1E-2
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
da/dN, mm/cycle
100
1000
10000
DeltaK mpa*sqrt(mm)
Steels R= 0.7 to 1.0
700
BHN
600
500
400
300
200
100


1E-2
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
da/dN, mm/cycle
100
1000
10000
DeltaK mpa*sqrt(mm)
R= -1
Steels R= -0.7 to -1
700
BHN
600
500
400
300
200
100

Summary:

1. Having a data base for da/dN curves is useful when checking a new or old single data set.

2. Our data plots are similar to the ASME lines and to the thresholds proposed by Hasegawa et al.

3. We will place our data collection plots on the web with an option for a student, or any other researcher, to check a specific da/dn curve against the "Forest" of available da/dN curves.

References

1. M.H.El-Haddad, "A Study of the Growth of Short Fatigue Cracks Based on Fracture Mechanics, PhD Thesis, Dept. of Civil Engr., U. of Waterloo, Canada, Aug. 1978

2. BS7910-2005, "Guide to methods for assessing the acceptability of flaws in metallic structures," British Std.

3. P. Dindinger, Stork Inc, Oct 12, Presented at F.D.E. Milwaukee Meeting, 2013.

4. J.C.Newman Jr, B.M.Ziegler J.W.Shaw T.S.Cordes D.J.Lingenfelser, "Fatigue Crack Growth Rate Behavior of A36 Steel using ASTM Load-Reduction and Compression Precracking Test Methods," Paper ID JAI103966 J. of ASTM International, V9 N4 2012

5. D.J.Klingerman, K.H.Frank, J.W.Fisher, "Fatigue Crack Growth in A36 Steel", ONR, DoD, Lehigh Univ., Fritz Engr. Lab Rep. No. 358.31, May 1971

6. K.Hasegawa, B.Strnadel, S.Usami, V.Lacroix, "Fatigue Crack Growth Thresholds at Negative Stress Ratio for Ferritic Steels in ASME Code Section XI," J. of Pressure Vessel Tech., June 2019, V141 pg.031101-1

7. D.N.Lal, "The Combined Effects of Stress Ratio and Yield Strength on the LEFM Fatigue Threshold Condition," Fatigue Fract. Engr Maler. Sfrucr. V15 N12 pp.1199-1212, 1992

8. K.Hasegawa, Y.Yamaguchi, V.Mares, Yinsheng Li, "Fatigue Crack Growth Rates for Ferritic Steels Under Negative R Ratio,"Paper PVP2016-63872, Proc. ASME2016 Press.Vess.Piping Conf., PVP2016, Vancouver July17-21 2016

9. 2017 ASME Boiler and Pressure Vessel Code, Section XI Appendix A and C, American Soc. of Mech Engrs.

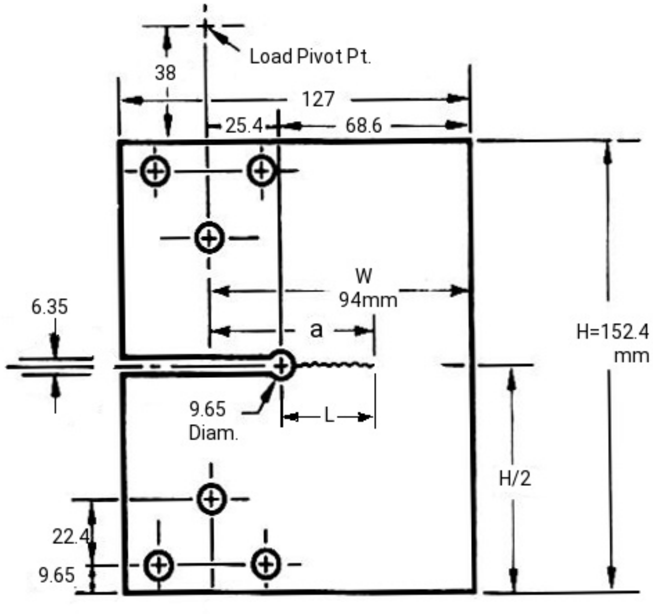
10. Tucker, L., S.Bussa, “The SAE Cumulative Fatigue Damage Test Program,” SAE paper 750038, Cong + Expon, Detroit, Feb.1975.

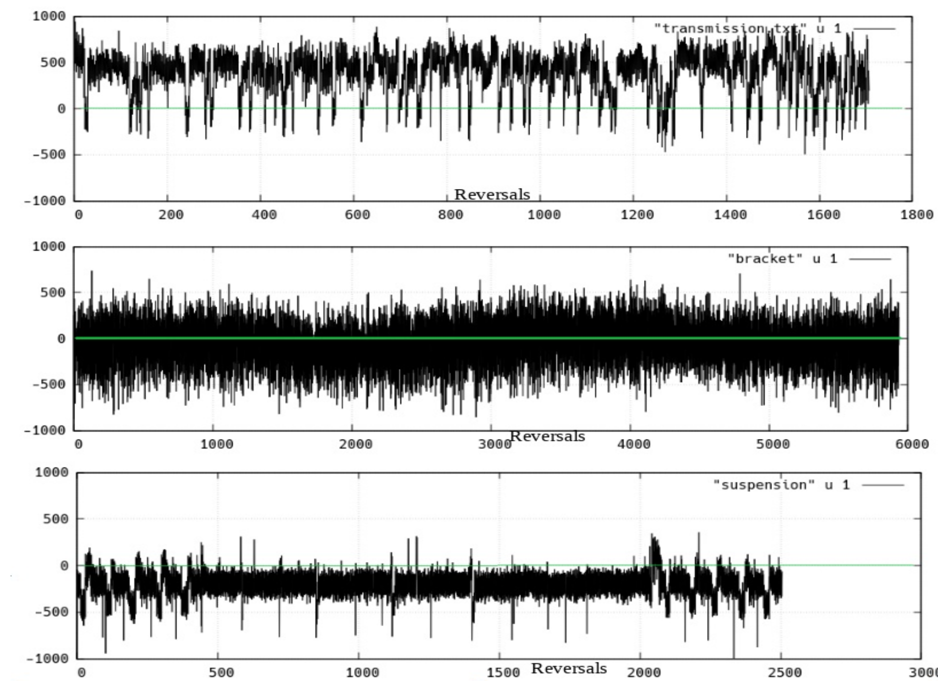
Sample Data file Format

```
# S355JR steel plate   BaseMetal        f=30hz  R-0.1
# Equiv.: ASTM A572,  CDN 350W
# CT spec. 87.5x84x15mm W=70mm, crack length via optical micros.
# Chem.: Nominal BM:Max Values!  0.24C 1.50Mn .55Si .040P
# Chem.: .040S .012N .55Cu
# Ref.: M,Benedetti1 V.Fontanari  L.Battisti, "Structural health
# Ref.: monitoring of wind towers: residual fatigue life
# Ref.: estimation," Smart Materials and Structures, V22, N4 Mar.2013
# Paper also contains data for weld metal and for HAZ
# Observed: "Apparently, the cracks initiated in the HAZ spontaneously
# tend to propagate outside the HAZ towards the BM."

#Sy= 380 mpa
#Su= 560 = 81.2 ksi
#BHN= 169  converted from Su
#%Elongation= 30 %  total

## convert2MPa_mm  vers. 1.7 starts...
#OriginalName= benedetti-S355JR_BM_R=0.1raw
#Got Original #dadnunits= m
#Got Original #deltaKunits= mpa_m
## 1 ksi*sqrt(inch) = 34.7485  Mpa*sqrt(mm)
## 1 ksi*sqrt(inch) = 1.0989   MPa*sqrt(m)
## 1 MPa*sqrt(m)  =   31.6228  N/(mm**(3/2) )
## 1 MPa*sqrt(mm) =         1  N/(mm**(3/2) )
## 1 MN*m**(-3/2) =   31.6228  Mpa*sqrt(mm)
## 1 kg*(mm^(-3/2)  =  9.80665 MPa*sqrt(mm)
#All inputs converted to    MPa*sqrt(mm)   and  mm/cycle
#Note that this is same as  N/(mm**(3/2))  and  mm/cycle
#deltaKunits=  mpa_mm
#dadnUnits= mm

## MPa*sqrt(mm) mm/Cycle    BHN  Su  Sy  R  Hz
 324.  0.3027E-06 169 560 380 0.1 30
 325.  0.1114E-05 169 560 380 0.1 30
 327.  0.1485E-05 169 560 380 0.1 30
 329.  0.1349E-05 169 560 380 0.1 30
 331.  0.1703E-05 169 560 380 0.1 30
 348.  0.4791E-05 169 560 380 0.1 30
 377.  0.5723E-05 169 560 380 0.1 30
 423.  0.7981E-05 169 560 380 0.1 30
 451.  0.1002E-04 169 560 380 0.1 30
 499.  0.1829E-04 169 560 380 0.1 30
 593.  0.3463E-04 169 560 380 0.1 30
 666.  0.7937E-04 169 560 380 0.1 30
 763.  0.1067E-03 169 560 380 0.1 30
 894.  0.2086E-03 169 560 380 0.1 30
1019.  0.3086E-03 169 560 380 0.1 30
1318.  0.5949E-03 169 560 380 0.1 30
1620.  0.8260E-03 169 560 380 0.1 30
```

Sample Gnuplot Script

```
 set term qt enhanced font "liberation serif,12" size 1200,900
set logscale x
set logscale z
set key outside
set xrange [50:10000]
set yrange [-1:1.0]
set zrange [*:*]
set format z '%.0tE%+T'
set xlabel "{/Symbol D}K  mpa*sqrt(mm)"
set ylabel "R"
set zlabel "da/dN, mm/cycle" rotate by 90
unset key
set pointsize 0.6
set colorbox default
set cbrange [100:700]

set palette   #This will reset to default

 set view 64, 322, 1, 1.4
 splot 'barsom12Ni_R=0.1_mpa.dadn'       u 1:6:2:3 w p lc palette , \
 'barsom12Ni_R=0.2_mpa.dadn'             u 1:6:2:3 w p lc palette , \
...etc
```





https://fde.uwaterloo.ca/Fde/Loads/Keyhole/keyholeSpec.Histories.pdf

F.D.E Keyhole
test data now
on web.