

明治大学学術フロンティア  
信頼性データバンク疲労データシート

**Meiji University Academic Frontier  
Reliability Data Bank Fatigue Data Sheet**

炭素鋼 C0.55%+x 両振りねじり疲労特性データシート

Data Sheet on Fatigue Properties of S55Cx Steel (HRC60)

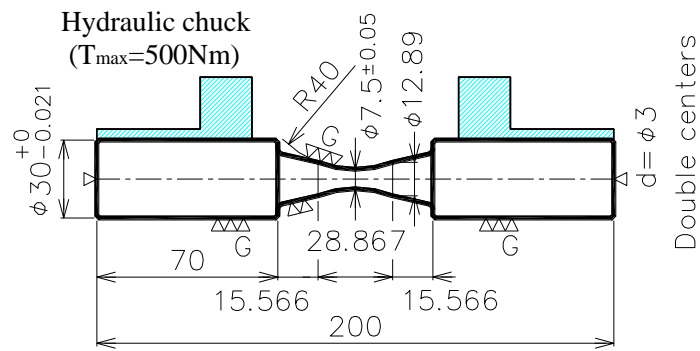
by Alternating Torsion Life Test

and

CFRP Plate Alternating Bending Test data in Case of Showing Fatigue

Limit

15. 02. 2007

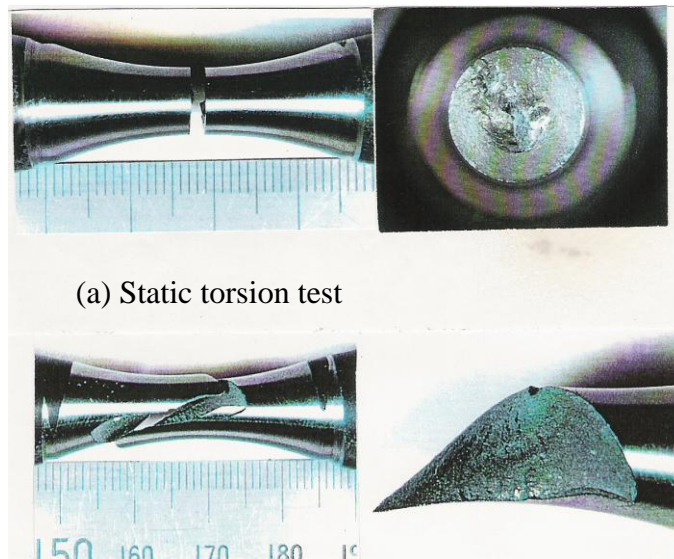


Test piece (S55Cx, C0.55%, HRC62 ~ 64)

Experimental conditions for alternating test

Mechanism	$\tau$ GPa	Cycles / m
Piston crank	1.0	300
	0.8	300
	0.7	450
	0.6	450
Lever crank	0.44	700
	0.22	1000

Fig.1 Test piece and experimental conditions for alternating torsion test



(a) Static torsion test

(b) Alternating torsion test

Fig.2 Static and alternating torsion failure mode

Table.1 Number of stress cycles to failure of alternating torsion fatigue life test data for S55Cx ball guide rail use steel (HRC60~64) [1]

Failure order	Number of stress cycles $N$ at stress amplitude $\tau$ GPa					
	1	0.8	0.6	0.5	0.44	0.22
1	8308	40574	300195	972654	2604000	1.5E+08
2	8792	44164	319595	1157053	2906500	Suspension
3	8941	46768	321685	1220890	3002900	-
4	8983	47491	424991	1330917	3108473	-
5	9361	50243	483494	1488805	3253300	-
6	9818	50378	484783	1538614	3430600	-
7	10334	54727	490592	1590374	3520000	-
8	10743	63919	516778	1653540	3692200	-
9	11088	64088	527852	1654005	3724900	-
10	11247	64126	613362	1684445	3858000	-
11	11501	66081	636417	1907622	3884000	-
12	12096	66979	664866	1989348	3998300	-
13	12247	69301	682185	2169452	4130700	-
14	13040	70169	739622	2471546	4305300	-
15	13294	71580	801598	2549351	4490300	-
16	14149	78889	819648	2585880	9317900	-
17	14204	78983	909448	3244251	9405400	-
18	16070	88484	1400944	3357944	9617500	-
19	16355	101683	-	4099211	9833900	-
20	-	106305	-	4766979	9858900	-
Sample size	19	20	18	20	20	2

- [1] Shimizu, S. (2006), “*Reliability Design for Mechanical System*,” 1<sup>st</sup> Edition, Surikogakusha, pp156-159 (in Japanese). “機械系のための信頼性設計入門”, 数理工学社
- [2] SHIMIZU, S.: P-S-N/P-F-L Curve Approach Using Three-Parameter Weibull Distribution for Life and Fatigue Analysis of Structural and Rolling Contact Components,” *Trib. Trans. STLE*, 48(2005), 1, 576-582.
- [3] Tanaka, T., Nishijima, N., and Ichikawa, M. (1987),”Statistical Research on Fatigue and Fracture,” *Elsevier Applied Science*, 159-176.

Table 2 Mechanical property for bearing steel S55Cx [2] and CFRP plate [3]

Bearing steel S55Cx (Correspond to 1055 SAE) Test result (HRC 60 ~ 64)	Carbon-fiber reinforced plastics, CFRP plate	
	Test results	Catalogue values
Proportional limit: GPa $\tau_p = N(0.72, 0.05^2)$	Density: g/cm <sup>3</sup> $N(1.59, 0.008^2)$	Tensile strength: MPa 561
	Flexural strength: MPa	
Shearing strength: GPa $\tau_u = N(2.26, 0.1^2)$	$N(850, 54^2)$	941
	Flexural modulus: GPa	
Tensile strength: GPa $\sigma_u = N(3.2, 0.215^2)$	$N(65, 1.8^2)$	63
	Interlaminar shear strength: MPa	
	$N(56, 6^2)$	76

### Result of Data Analysis for Fig.3 to Fig.12

Table 3 Comparison between MLS estimations and Normalized estimations by 3-parameter Weibull analysis for alternating torsion fatigue test, S55Cx [2]

$\tau$ GPa	Method of Least Sqs.			Common lives		Normalized Weibull slope		
	$\hat{m}$	$\hat{\eta} \cdot 10^3$ Cycle	$\hat{\gamma} \cdot 10^3$ Cycle	$L_{10} \cdot 10^3$ Cycle	$L_{50} \cdot 10^3$ Cycle	$\hat{m}$	$\hat{\eta} \cdot 10^3$ Cycle	$\hat{\gamma} \cdot 10^3$ Cycle
1	1.8	5	7	8.4	11.1	1.5	4.7	7.4
0.8	1.63	33	37	45.3	63.4		32.2	38.1
0.6	1.62	428	232	338.7	573.3		418.9	245.3
0.5	1.3	1480	804	1066	1920		1525	725.9
0.44	1.3	4050	2000	2717	5055		4174	1786

Table 4 Final equations for  $P - S - N$  curves at  $n\%$  probability of failures, S55Cx.

Conventional	$\gamma = 7993 \tau^{-6.61} = \left(\frac{\tau}{3.89}\right)^{-6.61}$ , By normalized $m = 3/2$	
$N_{10} = 8979 \tau^{-6.98}$	$N_{10} - \gamma = 1120 \tau^{-8.3}$	$N_n = \left(\frac{\tau}{2.33}\right)^{-8.3} \left(\frac{\ln R}{\ln 0.9}\right)^{\frac{2}{3}} + \left(\frac{\tau}{3.89}\right)^{-6.61}$
$N_{50} = 11600 \tau^{-7.43}$	$N_{50} - \gamma = 3938 \tau^{-8.3}$	
$N_{90} = 16417 \tau^{-7.75}$	$N_{90} - \gamma = 8765 \tau^{-8.3}$	

Table 5 Comparison between MLS estimations and Normalized estimations by 3-parameter Weibull analysis for alternating bending test, CFRP plate [3]

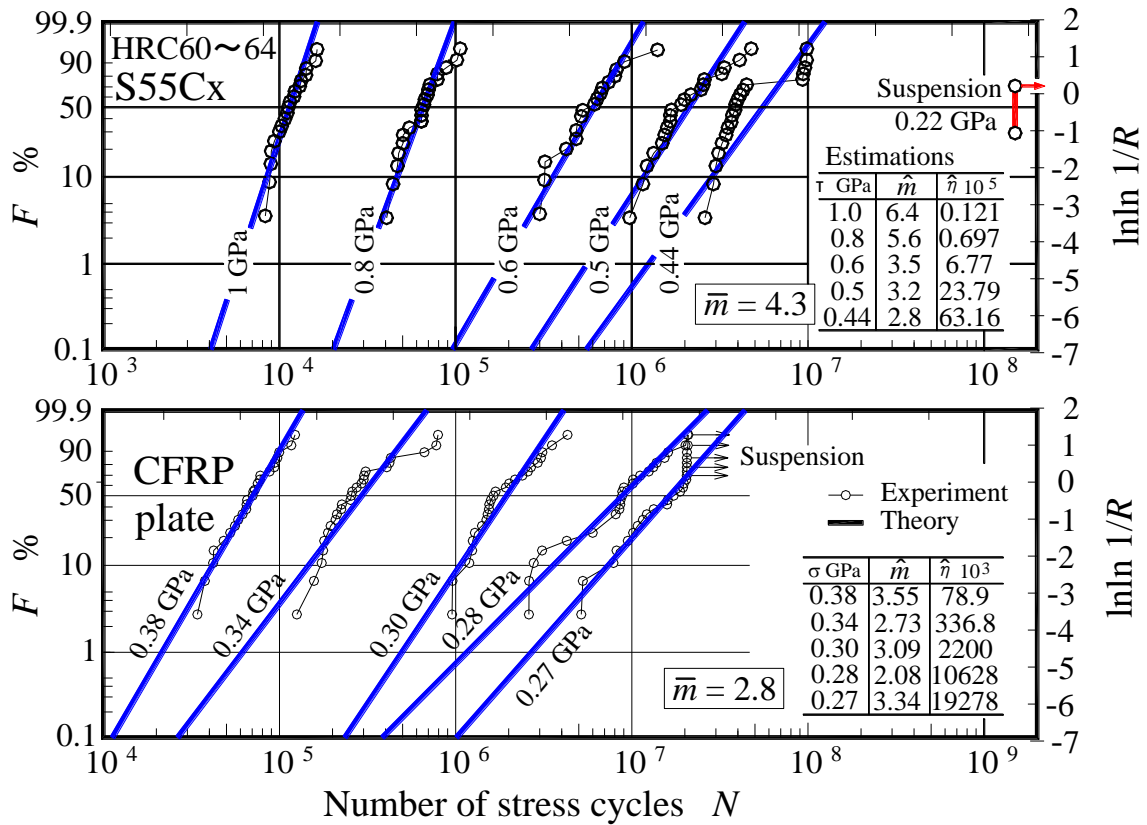
$\sigma$ GPa	Method of Least Sqs.			Common lives		Normalized Weibull slope		
	$\hat{m}$	$\hat{\eta}$ 10 <sup>3</sup> Cycle	$\hat{\gamma}$ 10 <sup>3</sup> Cycle	$L_{10}$ 10 <sup>3</sup> Cycle	$L_{50}$ 10 <sup>3</sup> Cycle	$\hat{m}$	$\hat{\eta}$ 10 <sup>3</sup> Cycle	$\hat{\gamma}$ 10 <sup>3</sup> Cycle
0.38	2.10	54.1	23.7	42.2	69.1	1.5	48.0	31.5
0.34	1.48	167	123	159.5	253.4		168	122
0.30	1.23	1240	860	1059	1780		1290	772
0.28	1.25	8390	1940	3328	8200		8700	1390
0.27	1.27	17700	3960	6969	17222		18310	2890

Table 5 Final equations for  $P - S - N$  curves at  $n\%$  probability of failures, CFRP plate.

Conventional	$\gamma = 0.120(\sigma - 0.0234)^{-12.1} = \left(\frac{\sigma - 0.0234}{0.84}\right)^{-12.1}$ , By normalized $m = 3/2$	
$N_{10} = 3.93(\sigma - 0.2)^{-5.41}$	$N_{10} - \gamma = 2.91(\sigma - 0.237)^{-4.2}$	$N_n = \left(\frac{\sigma - 0.237}{1.29}\right)^{-4.2} \left(\frac{\ln R}{\ln 0.9}\right)^{\frac{2}{3}} + \left(\frac{\sigma - 0.0234}{0.84}\right)^{-12.1}$
$N_{50} = 16.1(\sigma - 0.226)^{-4.46}$	$N_{50} - \gamma = 10.2(\sigma - 0.237)^{-4.2}$	
$N_{90} = 29.2(\sigma - 0.231)^{-4.33}$	$N_{90} - \gamma = 22.8(\sigma - 0.237)^{-4.2}$	

# Example of Data Analysis

Material showing no fatigue limit



\*Weibull slope  $m$  values are not constant and scatter between  $m = 2.8$  to  $6.4$  for S55Cx steel and  $m = 2.08$  to  $3.55$  for CFRP plate, therefore we can not use for  $P-S-N$  curve analysis.

Fig.3 Alternating torsion and simple bending life test, analyzed by using 2-parameter Weibull distribution [1][2][3]

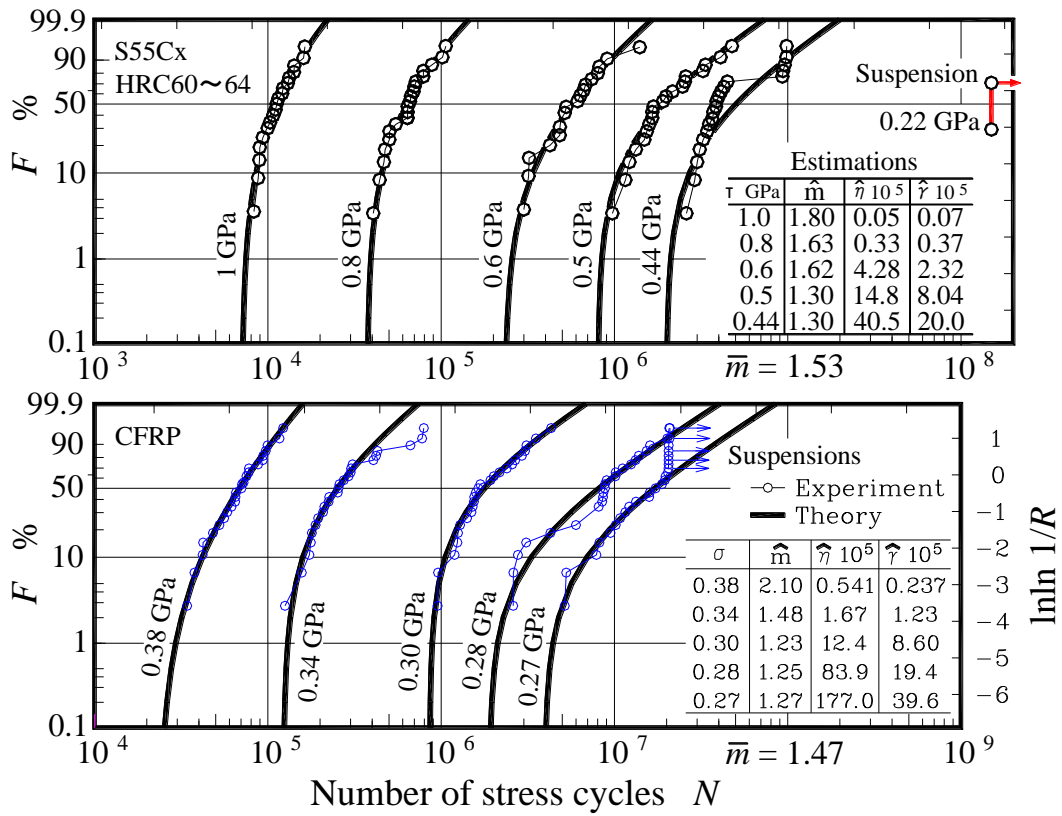
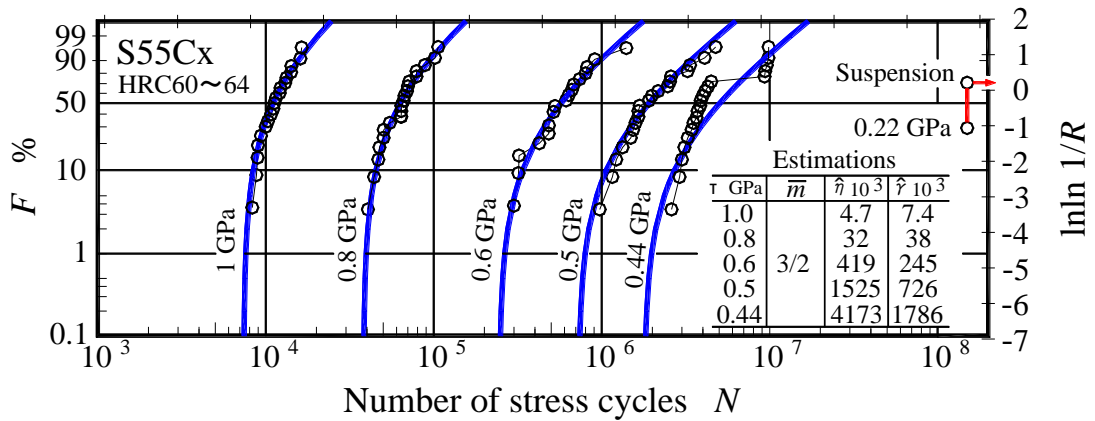
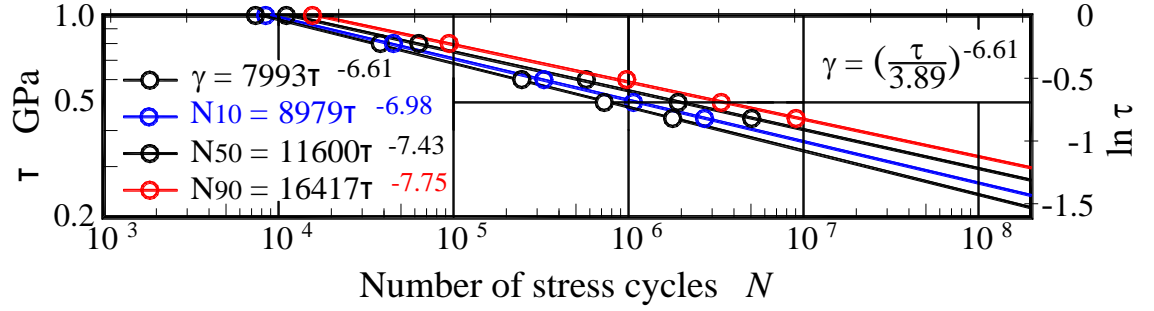


Fig.4 Conventional 3-parameter Weibull analysis for S55Cx and CFRP, obtained by method of least squares shown [1][2]



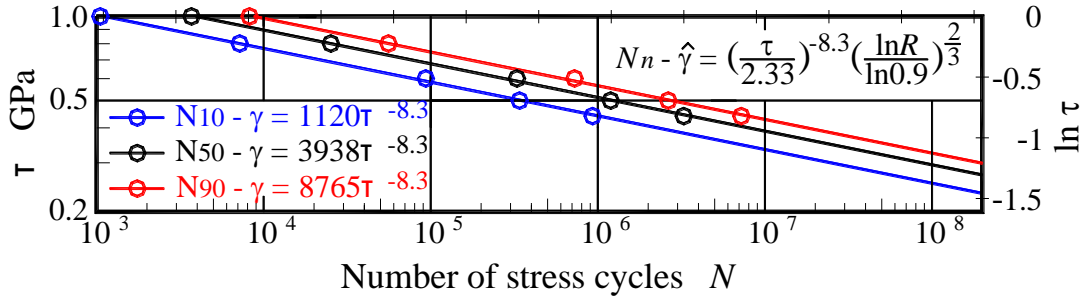
\*We must carried out for  $P-S-N$  curve analysis with constant Weibull slopes, therefore normalized Weibull analysis with mean of Fig.4 is carried out for life distribution in Fig.4.

Fig.5 Life distribution for S55Cx and Normalized Weibull analysis,  $m = 3/2$ , obtained by two-point estimation shown, using  $N_{10}$  and  $N_{50}$ [1][2]



$$N = BS^{-A}, \ln N = -A \ln S + \ln B \quad (1)$$

Fig.6 Linear regression of  $P$ - $S$ - $N$  curve by using equation (1),  $m = 3/2$  Normalized Weibull, ( $\hat{\gamma}$ 's obtained in Fig.5 are used)



$$N_n - \hat{\gamma} = a_1 \left( \frac{S - S_f}{C_s} \right)^{-A}, a_1 = \left( \frac{\ln R}{\ln 0.9} \right)^{1/m}, \ln(N_n - \hat{\gamma}) = -A \ln(S - S_f) + A \ln C_s + \ln a_1 \quad (2)$$

\* $C_s$  = 90% rating stress for 1 stress cycle and  $S_f$  = Fatigue limit, in this case  $S_f = 0$

Fig.7  $N_n - \hat{\gamma}$  plot and linear regression by equation (2),  $m = 3/2$  Normalized Weibull, ( $\hat{\gamma}$ 's obtained in Fig. 4 are used).

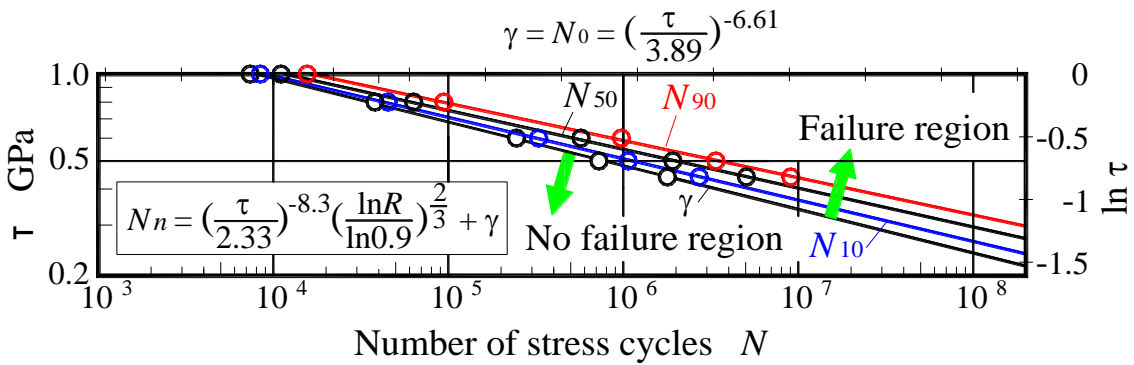


Fig.8 New  $P$ - $S$ - $N$  curve with  $m = 3/2$ ,  $A = 8.3$  and  $S_f = 0$  obtained from equation (2).

Material showing a fatigue limit

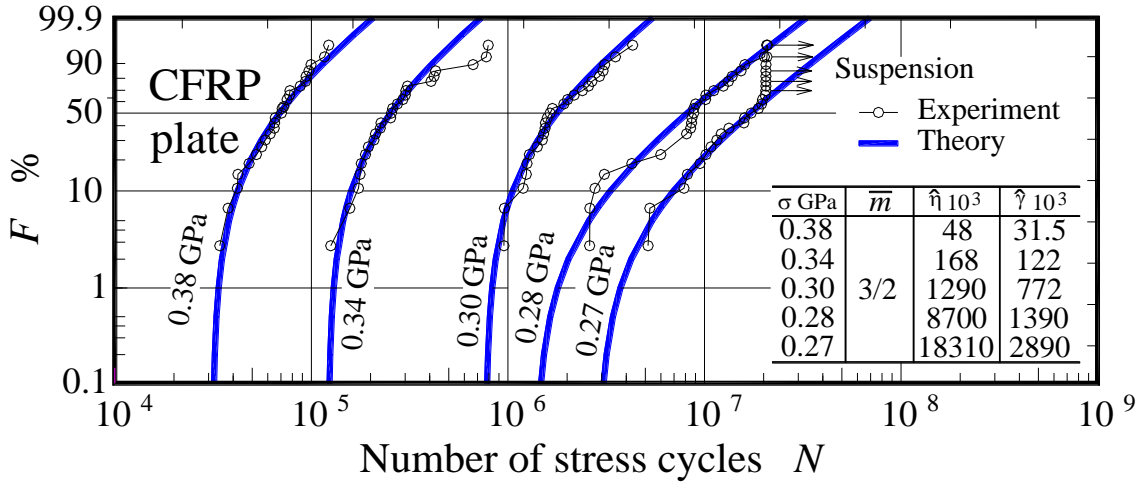
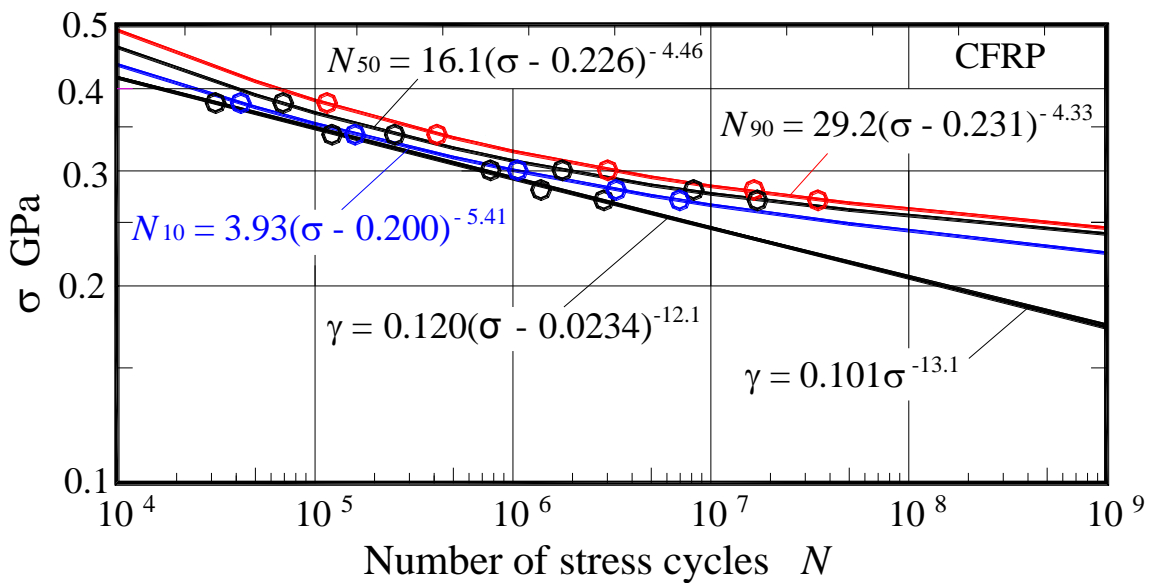


Fig.9 Life distribution for CFRP and  $m = 3/2$  Normalized Weibull analysis, obtained by two-point estimation, using  $N_{10}$  and  $N_{50}$  in Fig.4.



$$N = B(S - S_f)^{-A}, \ln N = -A \ln(S - S_f) + \ln B \quad (3)$$

\*Stress life exponent "A" values do not show a constant, therefore we can not use equation (3) for P-S-N data analysis.

Fig.10 Nonlinear regression of P-S-N curve for CFRP plate by using equation (3),  $m = 3/2$  Normalized Weibull, ( $\hat{\gamma}$ 's obtained in Fig.9 are used).

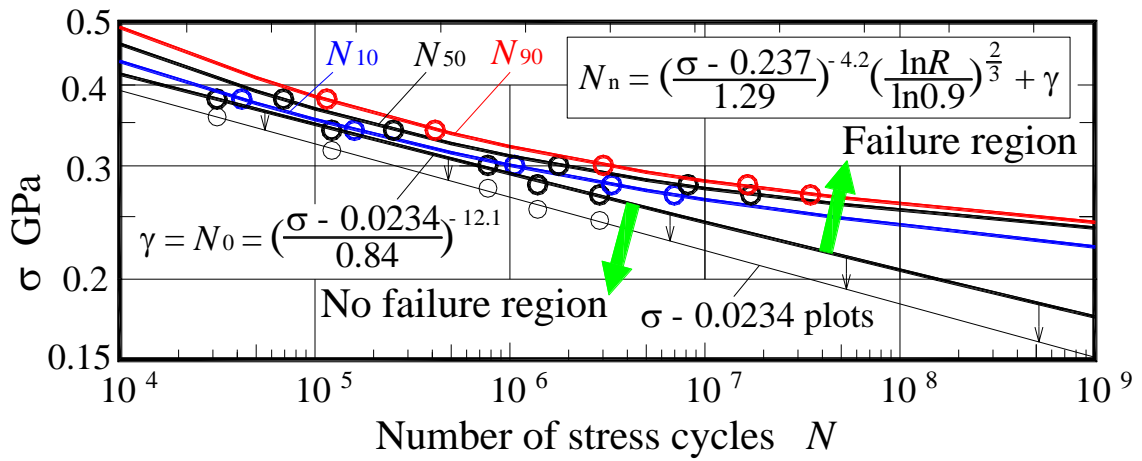
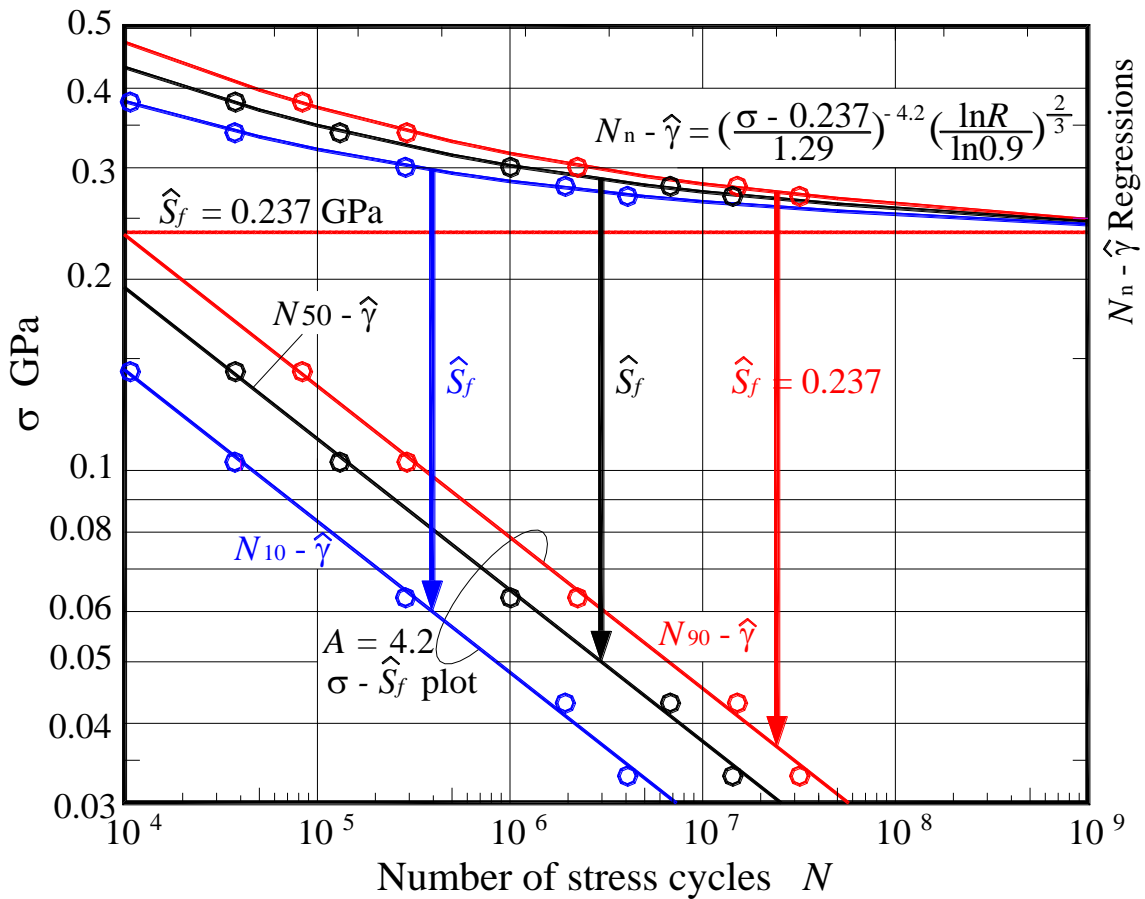


Fig.11 New P-S-N curve with  $m = 3/2$ ,  $A = 4.2$  and  $S_f = 0.237$  obtained from equation (2)



\* $N_n - \hat{\gamma}$  plots show us fatigue limit  $S_f = 0.237$  GPa clearly, therefore  $S - S_f$  plots show us linear regression with  $A = 4.2 = \text{constant value}$

Fig.12  $N_n - \hat{\gamma}$  ,  $S - \hat{S}_f$  plot and linear regression by equation (2),  $m = 3/2$  Normalized Weibull, ( $\hat{\gamma}$ 's obtained in Fig.11 are used)