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Method of Producing Improved Bearing Components by Elimination or Control of Fiber Orientation, Including Magnetic Analysis

MRC Proposal No. 1298 - 1382
Quarterly Report No. 7

Contract: NASA, Washington, DC
Contract No. NASw- 72

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Form 406

PROBLEM: Method of producing improved bearing components by elimination or control of fiber orientation.

OBJECT: To conduct experimental investigation of methods for reducing the amount of end grain fiber in a bearing component, to evaluate these various fabricating methods with regard to rolling contact fatigue life, and to investigate the magnetic properties of bearing components with regard to rolling contact fatigue life.

RESULTS: Rolling contact fatigue testing of five lots of balls - reference group, sintered group, pinch-off group, soft reference group, and peened balls - has been completed. Rolling contact fatigue testing data for these five lots of balls is presented in Tables I through V. Spall locations and the analysis of spall location with relation to polar end grain areas is presented in Tables VI through X. A summary of these data for each group of balls is compared in Table XI. Weibull diagrams for all groups of balls with exceptions of the sintered type is shown in Figures I through IV.

CONCLUSIONS: On the basis of test results obtained to date in this program, the following conclusions are made.

1) Heterogeneous balls (fabricated from powder compacted, sintered, and extruded rod) are unsatisfactory from a standpoint of bearing life.

2) Alternate forging methods ("pinch-off") designed to reduce polar end grain have resulted in decreased ball life, but a slight reduction in fatigue life scatter is noted.

3) Surface peening or alternate methods of surface working or hardening, i.e., explosive surface hardening, appear to offer the most promise as a method of increasing ball life.

4) Regardless of ball fabrication history, spalls occur predominantly on end fiber areas.

5) The effect of the percent reduction of the original ingot and the effect of inclusions on rolling contact fatigue life and the effect of these variables on the end fiber and subsequently on rolling contact fatigue life should be further evaluated.

DISCUSSION OF RESULTS:

As noted on previous lots of balls, etching revealed that a predominant number of spalls occurred in the end fiber of the peened group and the soft reference group of balls. Light streaks revealed by etching, running from pole to pole, were also found on these two lots of balls. Previous lots of SAE 52100 1/2" balls fabricated from the same lot of material have also exhibited these streaks, which have been identified as paraferrite, an intermediate product formed in the austenite - bainite transformation. Because of the directionality of these streaks (they follow original fiber orientation of the ball wire) this paraferrite condition is felt to be a result of segregation or some other inherent condition in the original ingot. Because of this condition a new lot of SAE 52100 ball wire has been ordered for future lots of balls to be fabricated in this study.

The second group of reference balls had been heat treated to Rc 58 so that a comparison could be obtained with the "pinch-off" group of balls which had been heat treated to a Rc 58. The "pinch-off" group of balls had a much lower average life than the "soft" reference group of balls, 12.67 x 10^6 stress cycles vs 39.78 x 10^6 stress cycles. A void in the Weibull diagram for the Rc 58 reference group was noted. Hardness measurements of all balls in this group showed them to be of a consistent hardness. The location of spalls in relation to end grain was not significant in explaining this void. As a result of this void the B 50 life of this group of balls was the highest of all lots tested.

The peened balls were finished to .490" diameter, erroneously. This fact was not discovered until rolling contact fatigue testing was completed. The .490" balls were run under the same test condition as the .500" balls. Calculations show that the actual contact angle was 28° 57' with a maximum Hertz Stress Level of 814,400 psi. The B 10 and B 50 life as presented in Table XI would be increased by a calculated factor of 1.195 if the contact angle had been 30° and maximum Herta Stress Level 800,000psi. Figure IV illustrates the Weibull diagram for the data obtained at a 28° 57' contact angle and a maximum Hertz Stress Level of 814,400 psi compared with the calculated Weibull diagram for a 30° contact angle and 800,000 psi. maximum Hertz Stress Level.

The hot peening of balls has not reduced the tendency of spalls to occur on end fiber areas of the ball nor has it reduced scatter to any significant extent. However, a substantial increase in average ball life was noted for this group of balls. The average life of the original reference group of balls was 45.74×10^6 stress cycles and the average life of the peened balls was 71.43×10^6 stress cycles under actual test condition.

The effect of hot surface peening on rolling contact fatigue life is not clear. Balls which were hot peened were .506" in diameter prior to peening, heat treatment, and finishing to .490". Micro-examination of a peen ball prior to heat treatment revealed an area penetrating approximately .0002" into the surface of the ball in which carbides appeared to be of a more uniform size and distribution. The depth of this observable penetration of the hot peening effect was, of course, removed during the finishing operation.

A modification of the original ball peening unit is being made so that closer temperature control can be maintained. Since the most encouraging results of all lots of balls tested were obtained from the peened balls, actual bearing assemblies will be tested using this type of ball.

FUTURE TESTING: The testing reported herein was conducted on five - ball test rigs at NASA Lewis Laboratory, Cleveland , Ohio. Subsequest testing shall be conducted on similar test rigs at MRC Research. These rigs have been constructed and are now being operated on "shakedown".

MRC alloy 52100 balls from the original reference group of balls will be run in these rigs to correlate test results with the results obtained on the NASA five - ball rest rigs. M-50 balls fabricated from longitudinal and transverse sections of cross rolled plate

(See: Quarterly Report No. 6) are to be tested on these rigs during the next quarter. M-50 balls fabricated from inside and outside a single billet will also be tested at this time. Preliminary test results from this billet were received from NASA but the number of tests was insufficient to establish a trend. The testing of these lots of balls and the bearing assemblies containing peened balls will conclude first phase work scheduled under this contract.

During this quarter, the scope of the contract was extended to permit testing of additional lots of balls with these objectives:

1) To expand investigation of methods of producing improved bearing components by elimination or control of fiber orientation.

2) To investigate the effect of forging or degree of working, on the structure of bearing components.

3) To study the significance of metallurgical characteristics by magnetic analogy.

4) To study magnetic properties of bearing materials in an attempt to correlate magnetic phenomena with rolling contact fatigue life.

The following lots of balls in the conditions indicated are to be obtained.

Material

Lot I - SAE 52100, vacuum induction melted, centerless ground, .375" dia. ball wire.

To be fabricated into .520" diameter balls by conventional methods prior to heat treatment. This lot of balls will then be separated into the following groups for further processing as indicated.

A) Reference Group

B) Harden and draw to Rc 60. Explosive surface harden. Finish to 1/2" diameter.

C) Harden and draw to Rc 40. Explosive surface harden. Finish to 1/2" diameter.

D) Explosive surface harden, Harden and draw to Rc 64. Finish to 1/2" diameter.

E) Hot peen at 600°F. Harden and draw to Rc 64. Finish to 1/2" diameter.

F) Hot peen at 900°F. Harden and draw to Rc 64. Finish to 1/2" diameter.

G) Hot peen at 1200°F. Harden and draw to Rc 64. Finish to 1/2" diameter.

Material

Lot II SAE 52100 vacuum induction melted, cast to a range of ingot sizes which can be hot forged to give known percent reductions in cross - sectional area. Reductions will range from 0 to 95%. The resulting bars will be centerless ground to .375" diameter ball wire and fabricated by conventional methods into 1/2" balls.

Material

Lot III Three alloy 52100 vacuum induction melted heats will each have a type of inclusion (sulfides, aluminates, and silicates) added to the melt to obtain J-K ratings of 4-5. This material will be fabricated into 1/2" balls by conventional methods.

Material

Lot IV Consumable electrode melted M-50 stock.

Ausforming and peening in the ausforming temperature range are tentatively scheduled for investigation.

All lots of balls will be tested by MRC on five - ball test rigs to obtain rolling contact fatigue data.

A representative number of balls from each group in Material, Lot Number I will have hysteresis loops plotted and torque magnetometer readings taken prior to testing.

lbh

TABLE I
Marlin-Rockwell Corporation - NASA Fatigue Data

IX Series
30° Contact Angle
Speed: 10,233 RPM
Average Ambient Temperature: 155°F.

Reference Balls, 52100 Hardness: 64 Rc
Lubricant: 7808 Lubricant Flow: 16 gms/hr.
Maximum Contact Stress: 800,000 psi
Ball Weight: 8.35 gms.
Failure Index: 26 out of 39

Ball No.	Life (hrs.)
12	1.5
30	3.3
2	4.5
15	7.2
35	8.7
9	13.8
29	15.0
20	16.2*
16	16.3
14	17.2
4	21.1
21	25.5
1	28.4
3	28.5
17	29.8
8	30.1
32	31.1
18	39.5
26	40.3
23	55.7
31	57.5
13	83.4
38	96.9
7	123.3
25	129.5
36	131.3*
24	138.1
37	143.1
28	150.0*
39	150.1*
5	150.3*
34	156.6*
33	157.6*
6	158.5*
27	161.7*
40	166.0*
10	168.0*
11	168.2*
19	173.1*
22	Void

*Suspensions

TABLE II
Marlin-Rockwell Corporation @ NASA Fatigue Data

DL Series
30° Contact Angle
Speed: 10,233 RPM
Average Ambient Temperature: 100°F.

Sintered Balls, 52100 Hardness: 61 Rc
Lubricant: 7808 Lubricant Flow: 16 gms/hr.
Maximum Contact Stress: 800,000 psi
Ball Weight: 8.16 gms.
Failure Index: 20 out of 20

Ball No.	Life (hrs.)
6	0.05
1	0.10
2	0.10
3	0.10
4	0.10
5	0.10
7	0.10
9	0.10
10	0.10
11	0.10
12	0.10
13	0.10
14	0.10
15	0.10
16	0.10
17	0.10
18	0.10
19	0.10
20	0.10
8	0.15

TABLE III

Marlin-Rockwell Corporation - NASA Fatigue Data

DM Series
30° Contact Angle
Speed: 10,233 RPM
Average Ambient Temperature; 140°F.

Pinch Off Method, 52100 Hardness: Rc 58
Lubricant: 7808 Lubricant Flow 16 gms/hr.
Maximum Contact Stress: 800,000 psi
Ball Weight: 8.35 gms.
Failure Index: 37 out of 40

Ball No.	Life (hrs.)
1	0.7
3	0.7
5	1.3
17	1.5*
8	1.8
37	2.0
2	2.6
12	2.7
10	2.9
39	3.2
36	3.9
7	5.3
34	6.0
38	8.5
23	9.1
24	9.2
13	9.7*
21	10.5
9	11.3
6	11.6
27	11.6
40	12.1
32	12.3
28	12.7*
31	13.0
33	13.4
19	13.6
35	14.0
11	14.2
29	15.2
26	16.3
22	19.8
15	20.2
30	22.3
4	22.8
25	27.9
14	33.3
18	39.9
20	41.0
16	119.8

*Suspension

TABLE IV

Marlin-Rockwell Corporation - NASA Fatigue Data

DN Series
30° Contact Angle
Speed: 10,233 RPM
Average Ambient Temperature: 145°F.

Reference Balls, 52100 Hardness: Rc 58
Lubricant: 7808 Lubricant Flow: 16 gms/hrs.
Maximum Hertz Stress: 800,000 psi
Ball Weight: 8.35 gms
Failure Index: 22 out of 40

Ball No.	Life (hrs.)
8	1.9
14	2.5
4	3.0
13	2.9
6	2.9
15	3.0
40	3.8
23	4.1
7	4.6
21	5.8*
26	6.8
28	8.8
16	22.5
25	31.4
20	42.9
3	43.5
32	52.6
1	55.4
29	56.2*
39	65.0
33	103.2
9	126.3
36	146.5
2	148.4*
27	148.5
24	150.5*
19	150.5*
5	151.2*
31	151.6*
38	152.4*
11	160.5*
35	160.5*
30	160.7*
37	160.7*
17	162.8*
12	160.5*
22	164.0*
10	165.4*
18	165.9*
34	190.4*

*Suspensions

TABLE V
Marlin-Rockwell Corporation - NASA Fatigue Data

EB Series
28° 57' Contact Angle
Speed: 10,233 RPM
Average Ambient Temperature: 150°F.

Peened Balls, 52100 Hardness: Rc 64
Lubricant: 7808 Lubricant Flow: 16 gms/hr.
Maximum Hertz Stress: 814,400 psi
Ball Weight: 7.87 gms
Failure Index: 23 out of 41

Ball No.	Life (hrs.)
43	0.2
14	1.7
15	6.5
32	9.1
36	9.7*
24	9.7
33	10.8
6	12.3
10	18.4
27	25.9
13	27.3
2	28.2*
9	33.0*
8	37.1*
39	40.5*
5	41.4*
38	41.6*
35	42.0
22	45.3*
18	47.0
20	49.8
31	55.9*
16	60.8
40	67.2*
7	67.7*
29	71.5*
37	73.5
23	78.0*
30	87.8
12	92.0*
34	9617
19	101.7*
3	117.4*
42	126.7
17	132.7*
25	153.7
28	175.7
21	194.7
1	206.3
4	206.4
11	240.8*
26	Void
41	Void

*Suspensions

TABLE VI

REFEREE BALLS (DK SERIES)

Ball No.	Life (hrs.)	Location of Spall		% of Track on end grain
12	1.5	Spalled all around pole & equator	C	40.0
30	3.3	Center of pole	SC	33.0
2	4.5	22° from pole		38.75
15	7.2	Into pole		37.50
35	8.7	Wear Track Concentric with pole	SC	____(0°)
9	13.8	4° from pole		38.75
29	15.0	In pole area, strain cracks in track	SC	35.25
20	16.2*	____		____
16	16.3	Into pole		35.25
14	17.2	At very edge of pole		35.25
4	21.1	In equator	SC	58.0
21	25.5	Near Equator	SC	42.0
1	28.4	Through equator and into pole	C	34.0
3	28.5	36° from pole		16.0
17	29.8	In equator		45.5
8	30.1	Spalled all around pole & equator	SC	55.0
32	31.1	Just inside pole area		39.75
18	39.5	22° from pole		31.75
26	40.3	Thru equator	SC	38.75
23	55.7	Wear track concentric with pole		____ (0°)
31	57.5	In equator		45.5
13	83.4	7° from pole	SC	43.25
38	96.9	Across equator		44.25
7	123.3	Across all of pole area	SC	38.75
25	129.5	In equator	SC	30.75
36	131.3*	____		____
24	138.1	In pole	C	29.5
37	143.1	15° from pole		35.25
28	Suspended			
39	"			
5	"			
34	"			
33	"			
6	"			
27	"			
40	"			
10	"			
11	"			
19	"			
22	"			

*Suspended

C - Ball has streaks in grain flow direction

SC - Spalled in streak

Standard Deviation - 15.8

TABLE VII

SINTERED BALLS (DL SERIES)

Ball No.	Life (hrs.)	Location of Spall	% of Track on end grain
6	.05	5° from pole edge	47.75
1	.10	Thru Equator	39.75
2	.10	Extensive, but not in end grain	30.00
3	.10	Thru equator	37.50
4	.10	Thru equator	34.00
5	.10	Thru equator	34.00
7	.10	Thru equator	53.50
9	.10	Equator and Edge of pole	68.25
10	.10	Edge of equator	29.50
11	.10	Into equator	45.50
12	.10	In pole	31.75
13	.10	29° from pole	34.00
14	.10	In equator	50.00
15	.10	14° from pole	54.50
16	.10	In equator	45.50
17	.10	29° from pole	50.00
18	.10	In pole and touches equator	47.75
19	.10	On ddge of pole	41.00
20	.10	In euqator	34.00
8	.15	In pole, equator and in lateral area	43.25

TABLE VIII

"PINCH-OFF" BALLS (DM SERIES)

Ball No.	Life (hrs.)	Location of Spall
1	.7	11° from pole
3	.87	At edge of pole
5	1.3	Midway between poles
17	1.5*	--------------------
8	1.8	In pole
37	2.0	18° from pole
2	2.6	22° from pole
12	2.7	43° from pole
10	2.9	29° from pole
39	3.2	Midway between poles
36	3.9	7° from pole
7	5.3	In pole
34	6.0	Midway between poles
38	8.5	Midway between poles
23	9.1	11° from pole
24	9.2	Midway between poles
13	9.7*	____________________
21	10.5	Midway between poles
9	11.3	29° from poles
6	11.6	29° from pole
27	11.6	14° from pole
40	12.1	28° from pole
32	12.3	43° from pole
28	12.7*	---------------------
31	13.0	14° from pole
33	13.4	Midway between poles
19	13.6	43° from poles
35	14.0	22° from pole
11	14.2	29° from pole
29	15.2	29° from pole
26	16.3	Midway between poles
22	19.8	In pole
15	20.2	At edge of pole
30	22.3	At edge of pole
4	22.8	Midway between poles
25	27.9	Midway between poles
14	33.3	50° from pole
18	39.9	14° from pole
20	41.0	29° from pole
16	119.8	50° from pole

*Suspended

TABLE IX

SOFT REFEREE BALLS (DN SERIES)

Ball No.	Life (hrs.)	Location of Spall	% of Track on End Grain
* 8	1.9	Edge of Pole	31.8
*14	2.5	Side Grain through Streak	38.6
4	3.0	Edge of pole and hhrough center of Streak	43.8
13	2.9	Center of Pole	29.5
* 6	2.9	Edge of Pole through Streak	36.4
15	3.0	Edge of pole	34.1
*40	3.8	Side Grain	0.0
23	4.1	Side Grain	40.5
7	4.6	Side Grain	31.8
*26	6.8	Side Grain through Streak	37.5
*28	8.8	Equator through Streak	38.6
16	22.5	Side Grain	31.9
*25	31.4	Equator through Streak	46.5
20	42.9	Side Grain	29.5
* 3	43.5	Side Grain	28.1
*32	52.6	Equator	38.6
* 1	55.4	Equator	68.2
39	65.0	Side Grain	36.4
33	103.2	Edge of Pole	38.6
9	126.3	Edge of Pole	43.2
*36	146.5	Side Grain	34.1
27	148.5	Edge of Pole	45.0

* Paraferrite Streaks

TABLE X

Peendd Balls (EB Series)

Ball No.	Life (hrs.)	Location of Spall	% of Track on End Grain
43	0.2	Equator	54.5
14	1.7	Equator	53.3
15	6.5	Side Grain	0.0
32	9.1	Edge of Pole	41.0
24	9.7	Pole	36.5
33	10.8	Equator	42.1
6	12.3	Edge of Pole	33.0
*10	18.4	Side Grain through Streak	36.4
27	25.9	Side Grain extended into Equator	54.5
*13	27.3	Side Grain extending into Streak	0.0
35	42.0		37.5
18	47.0	Pole Area	48.8
*20	49.8	Side Grain through Streak	43.2
16	60.8	Equator	42.1
*37	73.5	Edge of Pole	34.1
*30	87.8	Equator	42.1
34	96.7	Edge of Pole	37.5
42	126.7	Side Grain	34.1
25	153.7	Side Grain	32.9
28	175.7	Across Equator to edge of Pole	38.7
*21	194.7	Side Grain extended into Pole	36.4
1	206.3	Edge of Pole	36.4
4	206.4	Equator	36.4

* Paraferrite Streaks

TABLE XI

SUMMARY OF ROLLING CONTACT FATIGUE TESTING DATA ON FIVE LOTS OF BALLS

	DK Series Reference Balls	DL Series Sintered Balls	DM Series Pinch-Off Balls	DN Series Reference Balls	EB Series Peened Balls
Average Life (hours)	45.74	0.10	12.67	39.78	71.43
Hardness (Rc)	64	61	58	58	64
Failure Index	26 of 39	20 of 20	37 of 40	22 of 40	23 of 41
End Grain (% of Track Length)	39.3	41.8	—*	36.5	38.3
Spalls in End Grain %	75	75	—*	54.5	65.2
Weibull Slope	1.07	-	.98	1.80	1.20
B 10 Life ($x 10^6$ stress cycles)	14.6	-	3.2	5.8	15.7
B 50 Life ($x 10^6$ stress cycles)	108.0	-	19.1	170	150

* Polar areas not defined by etching

Figure I

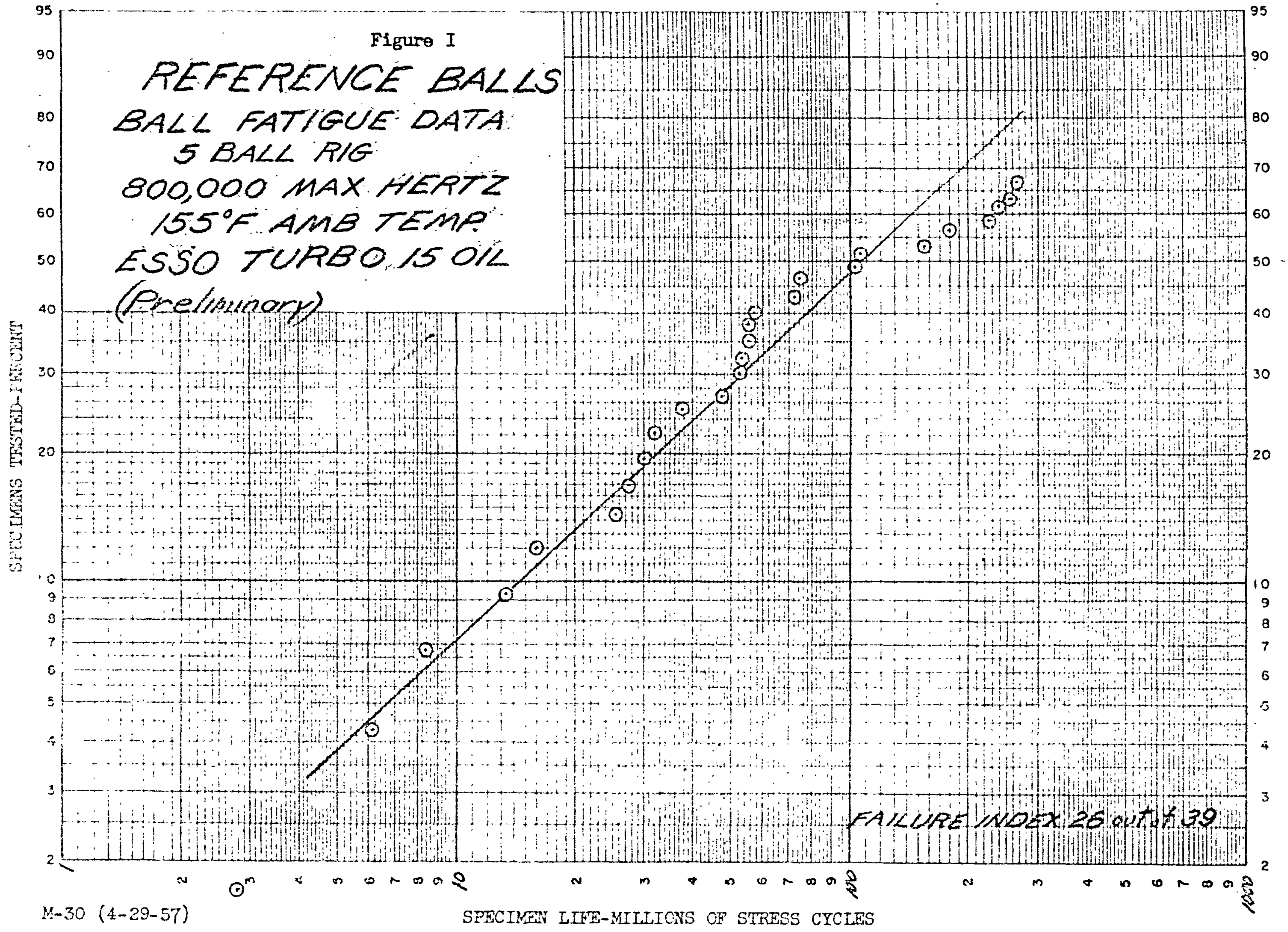


FIG I

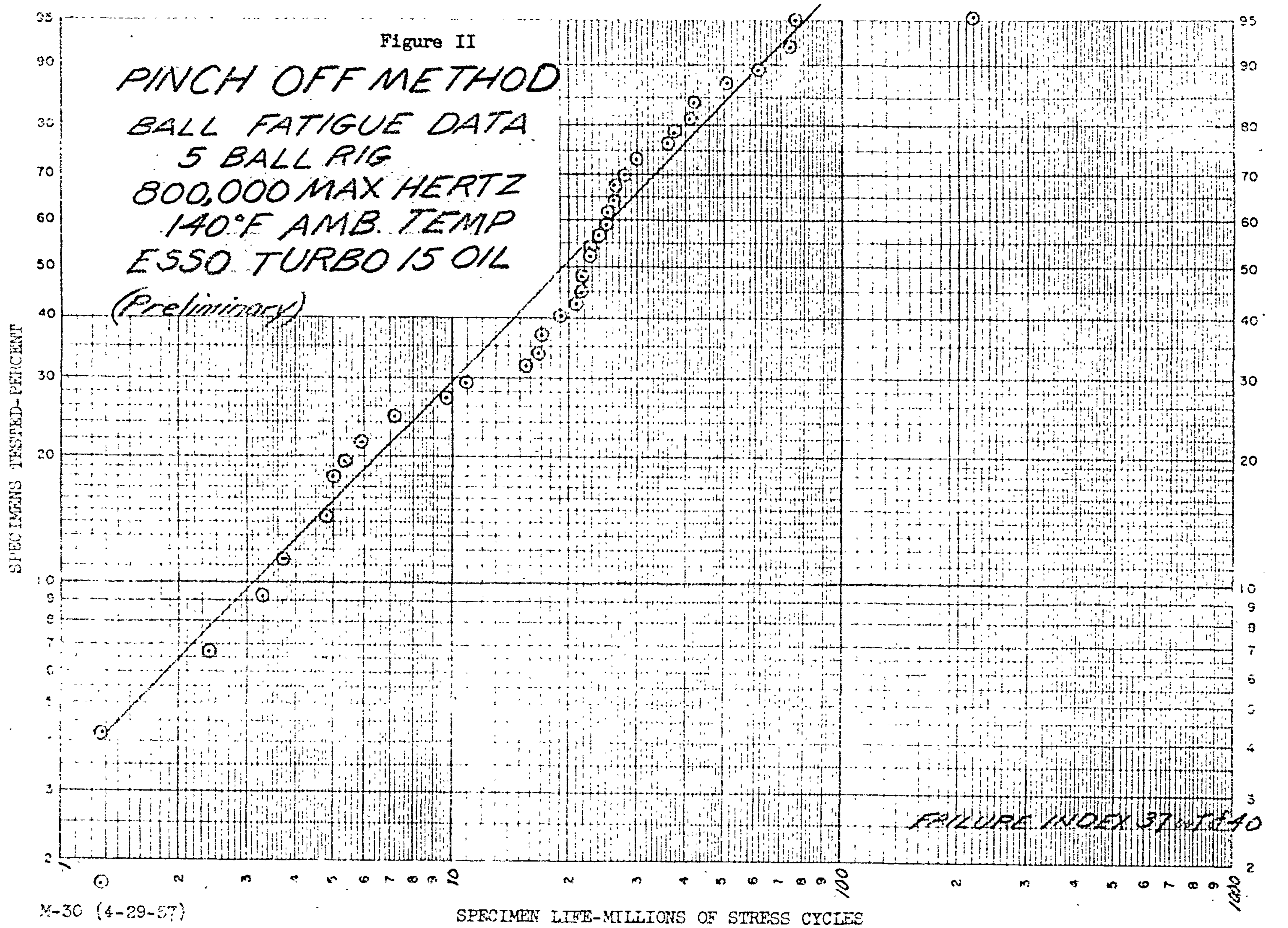
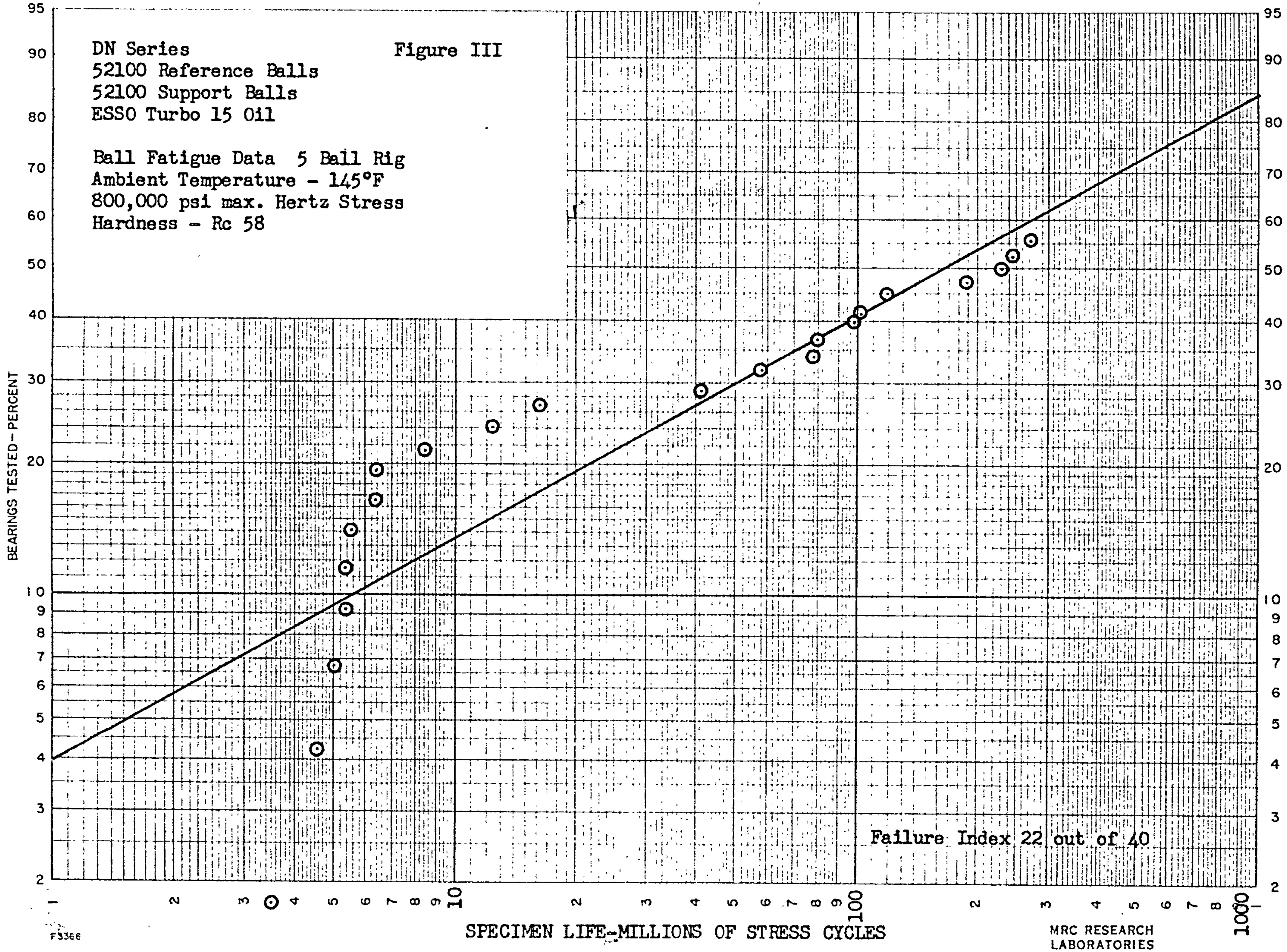
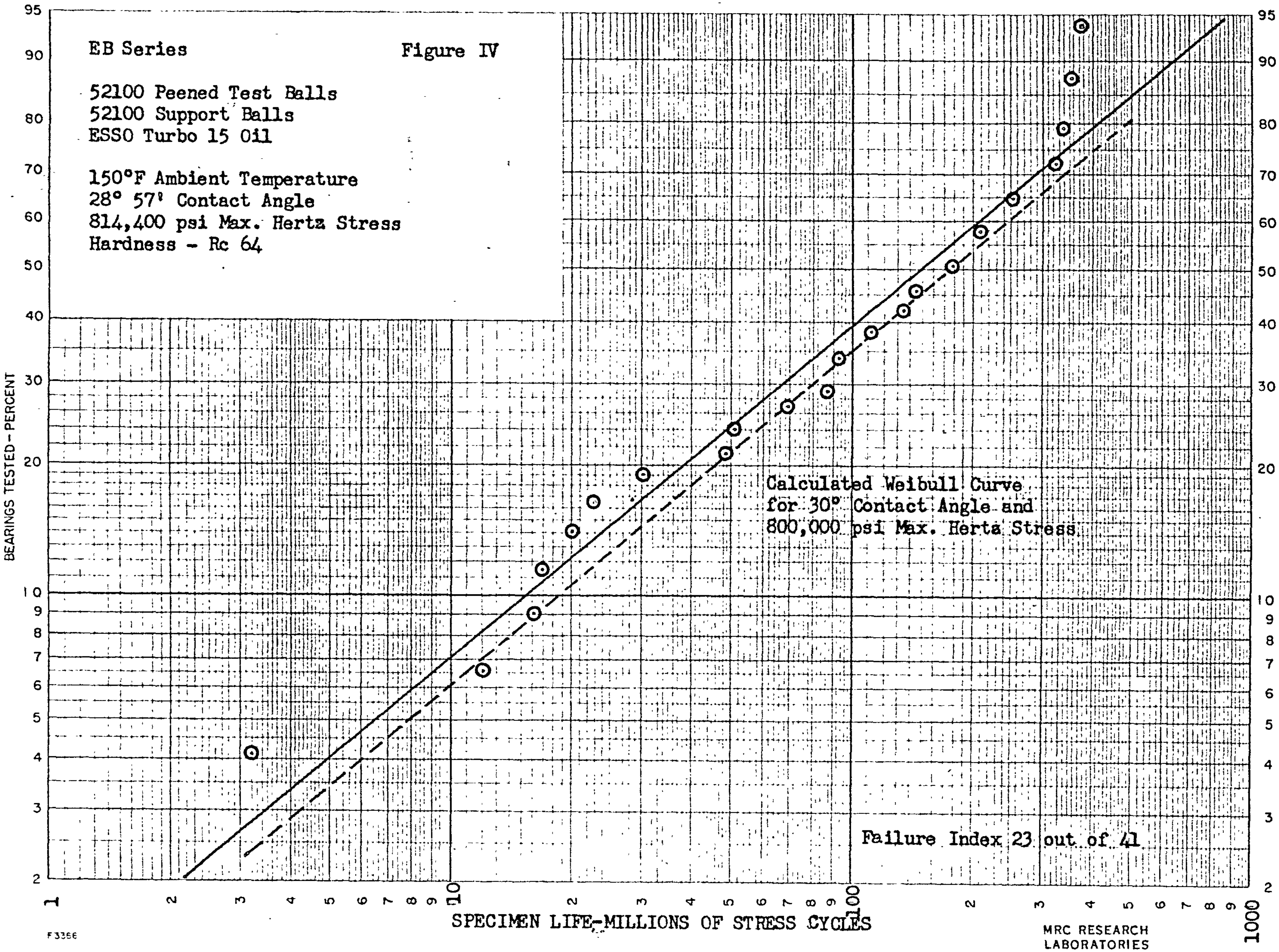


Figure II
PINCH OFF METHOD
BALL FATIGUE DATA
5 BALL RIG
800,000 MAX HERTZ
140°F AMB. TEMP
ESSO TURBO 15 OIL
(Preliminary)
SPECIMENS TESTED-PERCENT
SPECIMEN LIFE-MILLIONS OF STRESS CYCLES
M-30 (4-29-57)

FIG II



DN Series
52100 Reference Balls
52100 Support Balls
ESSO Turbo 15 Oil
Figure III
Ball Fatigue Data 5 Ball Rig
Ambient Temperature - 145°F
800,000 psi max. Hertz Stress
Hardness - Rc 58
BEARINGS TESTED-PERCENT
SPECIMEN LIFE-MILLIONS OF STRESS CYCLES
Failure Index 22 out of 40
MRC RESEARCH
LABORATORIES
F3366



EB Series
Figure IV
52100 Peened Test Balls
52100 Support Balls
ESSO Turbo 15 Oil
150°F Ambient Temperature
28° 57' Contact Angle
814,400 psi Max. Hertz Stress
Hardness - Rc 64
Calculated Weibull Curve
for 30° Contact Angle and
800,000 psi Max. Hertz Stress
Failure Index 23 out of 41
BEARINGS TESTED - PERCENT
SPECIMEN LIFE-MILLIONS OF STRESS CYCLES
F 3366
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