NASA
Technical
Paper
2080

January 1983

Rolling-Element Fatigue Life of AMS 5900 Balls

Richard J. Parker

NASA

NASA
Technical
Paper
2080

1983

Rolling-Element Fatigue Life of AMS 5900 Balls

Richard J. Parker
Lewis Research Center
Cleveland, Ohio

NASA
National Aeronautics
and Space Administration

**Scientific and Technical
Information Branch**

SUMMARY

The rolling-element fatigue life of VIM-VAR AMS 5900 12.7-mm (1/2-in.) diameter balls was determined in five-ball fatigue testers. Two groups of balls were tested which differed only by the process used to form the ball blanks before grinding. One group was cold headed, and the other was warm headed. Tests were run at a maximum Hertz stress of 5.52 GPa (800 000 psi), a shaft speed of 10 000 rpm, a contact angle of 30°, and a temperature of 339 K (150° F). A superrefined naphthenic mineral oil was used as the lubricant. The results were compared with results of tests at identical conditions with VIM-VAR AMS 5749 and VIM-VAR AISI M-50.

The 10-percent life with the warm headed AMS 5900 balls was equivalent to that of AMS 5749 and over eight times that of AISI M-50. AMS 5900 balls fabricated by cold heading had small surface cracks which initiated fatigue spalls where these cracks were crossed by running tracks on both upper or lower balls. The cold headed AMS 5900 balls had a 10-percent fatigue life an order of magnitude less than that of the warm headed balls even when failures on the cold headed balls at visible surface cracks were omitted.

INTRODUCTION

Rolling-element bearings for aircraft turbine-engine main shaft applications are generally specified to be made of AISI M-50 steel. Currently, the premium quality material used is double-vacuum melted (VIM-VAR for vacuum induction melt, vacuum arc remelt). This very clean, high quality material gives greatly improved rolling-element fatigue life over VAR or other air-or vacuum-melted materials.

Fatigue life is extremely important in the design and specification of rolling-element bearings, but fatigue is not a common failure mode in actual aircraft bearing experience, accounting for less than 10 percent of the total. A summary of causes for bearing rejection at a U.S. Navy facility (ref. 1) shows that corrosion accounts for nearly one-third of the bearing rejections from their aircraft systems, including drive lines, wheels, and accessories. Air Force experience (ref. 2) confirms that corrosion is a major cause of rejection at overhaul of aircraft turbine engine bearings. Bearing corrosion is more severe in systems with long periods of nonuse.

Steels such as AMS 5749 and AMS 5900 (commonly known as BG-42 and CRB-7, respectively) have been developed, that combine the tempering, hot hardness, and hardness retention characteristics of AISI M-50 steel with the corrosion and oxidation resistance of AISI 440C stainless steel. The typical chemical compositions of these materials are shown in table I. AMS 5749 and AMS 5900 contain higher percentages of carbon and chromium than AISI M-50 for improved corrosion and wear resistance. Their hot hardness and hardness retention are better than AISI 440C and similar to AISI M-50 (refs. 3 and 4).

Materials such as AISI 440C, AMS 5749, and AMS 5900 are called corrosion-resistant or stainless steels, but under some severe environmental conditions in aircraft bearings, they will corrode. They are, however, more corrosion resistant than the common aircraft bearing materials such as AISI M-50, AISI 52100 and the commonly used case-carburized materials.

AMS 5749 has shown excellent rolling-element fatigue life in the five-ball fatigue tests (ref. 5). Early rolling-element fatigue tests with AMS 5900 (then designated EX 00007) showed excellent results in a one-ball fatigue tester (ref. 4). These materials were both VIM-VAR processed and

TABLE I. - TYPICAL CHEMICAL COMPOSITIONS OF TEST MATERIALS

Material	Chemical composition,[a] wt. %						
	C	Si	Mn	Cr	Mo	V	Nb
AMS 5900	1.1	0.3	0.4	14.0	2.0	1.0	0.25
AMS 5749	1.15	.3	.5	14.5	4.0	1.2	----
AISI M-50	.85	.25	.35	4.0	4.25	1.0	----
AISI 440C	1.00	.5	.5	17.0	.5	---	----

[a]Balance iron.

showed lives greater than VIM-VAR AISI M-50 in these accelerated rolling-element fatigue tests. Further work with powder-processed VIM-VAR AMS 5900 was also reported in references 4 and 6. Accelerated fatigue tests in the one-ball tester and in the rolling-contact tester (RC rig) gave lives with powder-processed VIM-VAR AMS 5900 that were approximately twice that of conventionally processed VIM-VAR AISI M-50. Full scale ball bearings made of powder-processed VIM-VAR AMS 5900 (then designated CRB-7) gave fatigue lives approximately equal to that expected for VIM-VAR AISI M-50. An unresolved wear problem with the powder-processed AMS 5900 bearings somewhat offsets the encouraging fatigue life results.

The objectives of the work reported herein were to (1) determine the rolling-element fatigue life of conventionally processed VIM-VAR AMS 5900 and (2) compare the life results with similarly processed AMS 5749 and AISI M-50.

The first objective was accomplished by running a group of VIM-VAR AMS 5900 balls in five-ball fatigue testers. Test conditions included a shaft speed of 10 000 rpm, a contact angle of 30°, a maximum Hertz stress of 5.52 GPa (800 000 psi), and a temperature of 339 K (150° F).

TEST SPECIMENS

Two lots of 1.27-cm (1/2-in.) diameter, VIM-VAR AMS 5900 steel balls were each fabricated from single heats of material. The chemical compositions of the two lots are shown in table II. The balls were heat treated according to the specification of table III with the resulting hardnesses and retained austenite levels given in table IV. They were finished to AFBMA grade 10 specifications.

Lot A balls were formed by the more common cold heading procedures. On final inspection of the balls by the supplier, it was discovered that more than half of the 500-ball lot had visible surface cracks. These cracked balls were removed, and the remainder of the balls were accepted for test. It is suspected that the cracks occurred either during the cold heading procedure or during subsequent heat treatment. Previous unpublished experience shows that AMS 5900 is particularly susceptible to cracking as a result of the cold heading procedure. Macroetching of several of the visibly cracked lot A balls revealed that the cracks were located in the equator region formed as a result of the cold heading procedure. A typical crack visible on a finished lot A ball is shown in figure 1. Nearly all of the cracks observed were from 1.0- to 1.5-mm (0.04- to 0.06-in.) long.

Lot B balls were fabricated using a warm heading procedure, where the ball blanks were heated in a furnace to 1090 K (1500° F), removed, and

TABLE II. - CHEMICAL COMPOSITIONS OF AMS 5900 TEST LOTS

Lot	Chemical composition,[a] wt. %										
	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	V	Nb
A	1.12	0.30	0.40	0.014	0.003	14.22	0.11	2.08	0.09	1.02	0.31
B	1.09	.54	.29	.012	.007	13.97	.25	2.04	.02	1.10	.29

[a]Balance iron.

TABLE III. - HEAT TREATMENT OF TEST MATERIALS

Treatment	Material			
	AMS 5900		AMS 5749[a]	AISI M-50
	Lot A	Lot B		
Harden	In salt at 1422 K (2100° F)	In salt at 1422 K (2100° F)	In salt at 1422 K (2100° F)	In salt at 1403 K (2065° F)
Quench	In oil at room temperature	In salt at 866 K (1100° F)	In oil at 339 K (150° F)	In salt at 825 K (1025° F)
Stress relieve (or temper)	422 K (300° F) for 1 hr	783 K (950° F) for 2 hr	422 K (300° F) for 1 hr	811 K (1000° F) for 2 hr
Deep freeze	189 K (-120° F) for 2 hr	189 K (-120° F) for 2 hr	200 K (-100° F) for 15 min	183 K (-130° F) for 1.5 hr
Temper	797 K (975° F) for 2 hr; air cool	783 K (950° F) for 2 hr; air cool	797 K (975° F) for 2 hr; air cool	811 K (1000° F) for 2 hr; air cool
Deep freeze	---------------	189 K (-120° F) for 2 hr	---------------	--------------
Temper	797 K (975° F) for 2 hr; air cool	783 K (950° F) for 2 hr; air cool	797 K (975° F) for 2 hr; air cool (repeat 3 more times)	797 K (975° F) for 2 hr; air cool

[a]Lot C from reference 5.

headed before the blank temperature dropped to 922 K (1200° F). All lot B balls were free of visible surface cracks. Photomicrographs of sections of lot A and lot B balls, etched to show carbide size and distribution, are shown in figure 2. Little difference is observed between the two lots, except that lot A appears to have more numerous smaller carbides.

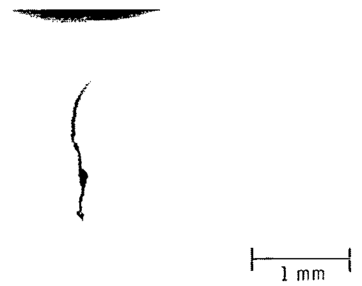
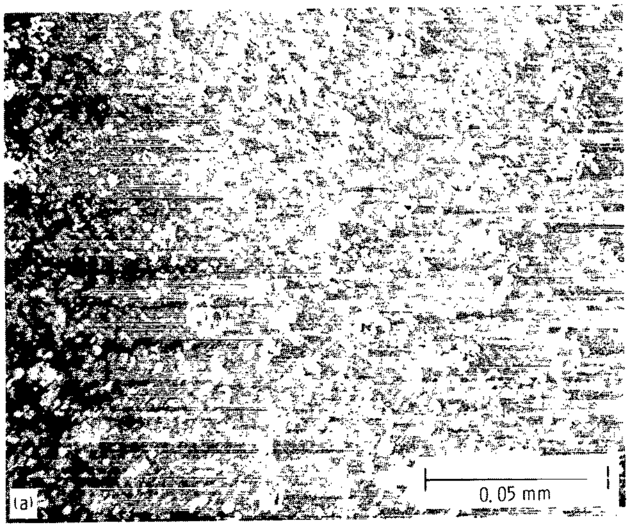
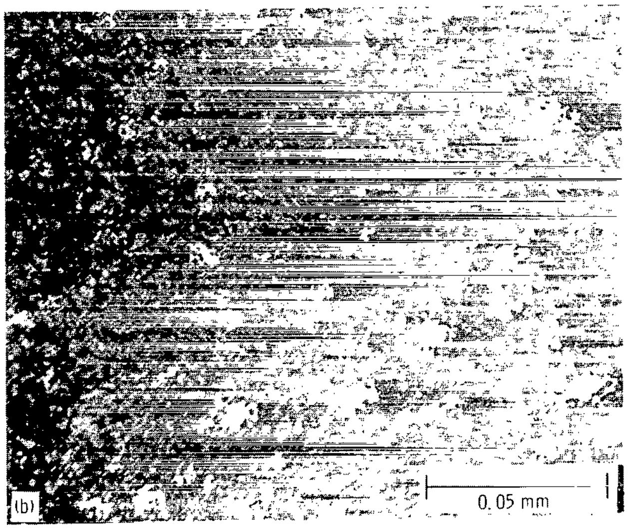


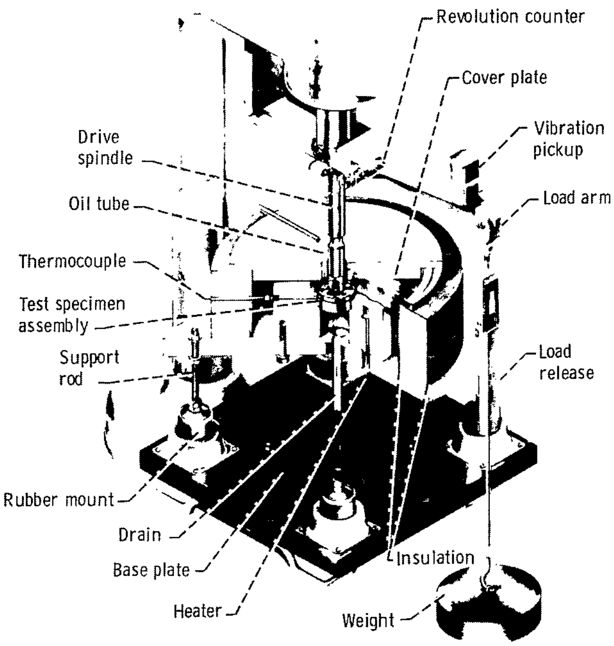
Figure 1. - Typical crack on a finished lot A AMS 5900 ball.



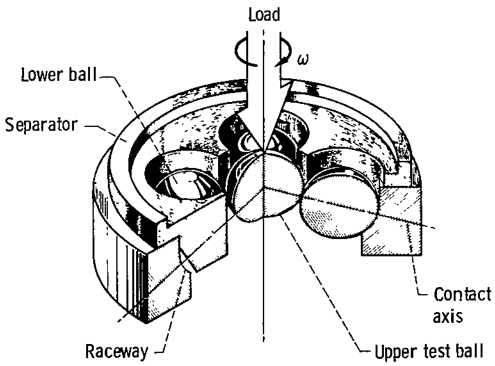


(a) Lot A, cold-headed.
(b) Lot B, warm headed.

Figure 2. - Typical structure of AMS 5900 balls.



(a) Cutaway view of five-ball fatigue tester.



(b) Five-ball test assembly.

Figure 3. - Test apparatus.

TABLE IV. - HARDNESS AND RETAINED AUSTENITE OF TEST MATERIALS

Material	Lot	Hardness, Rockwell C	Retained austenite,[a] vol. %
AMS 5900	A	61.4±1.8	<3
AMS 5900	B	61.9±0.5	<3
AMS 5749	(b)	64.1±0.5	6.3
AISI M-50	---	63.3±0.5	2.1

[a]As measured by X-ray diffraction technique.
[b]Lot C from ref. 5.

APPARATUS AND PROCEDURE

Five-Ball Fatigue Tester

The NASA five-ball fatigue tester was used for all tests conducted (fig. 3, ref. 7). This fatigue tester consists essentially of an upper test ball pyramided on four lower balls that are positioned by a separator and are free to rotate in an angular-contact raceway. System loading and drive are supplied through a vertical drive shaft, which grips the upper test ball. For every revolution of the drive shaft, the upper test ball receives three stress cycles from the lower balls. The upper test ball and raceway are analogous in operation to the inner and outer races of a bearing, respectively. The separator and lower balls function in a manner similar to the cage and the balls in a bearing.

Lubrication was provided by a once-through, mist lubrication system. The lubricant was a superrefined naphthenic mineral oil with a viscosity of 79×10^{-6} m^2/sec (79 cS) at 311 K (100° F) and 8.4×10^{-6} m^2/sec (8.4 cS) at 372 K (210° F). Vibration instrumentation was used to detect fatigue failure on either the upper or the lower ball and automatically shut down the tester. This provision allowed unmonitored operation and a consistent criterion for failure.

Fatigue Testing

Before they were assembled in the five-ball fatigue tester, all test-section components were flushed and scrubbed with ethyl alcohol and wiped dry with clean cheesecloth. The test assembly was coated with lubricant to prevent wear at startup. A new set of five balls was used for each test. Each test ended when a fatigue failure occurred on any test ball or when a preset cutoff time was reached. The speed, outer-race temperature, and oil flow were monitored and were recorded at regular intervals. After each test the outer race of the five-ball system was visually examined for damage. If any damage was discovered, the race was replaced before the next test was started. The stress that was developed in the contact area was calculated by using the Hertz formulas of reference 8.

Method of Presenting Fatigue Results

The statistical methods of reference 9 for analyzing rolling-element fatigue data were used to obtain a plot of the log-log of the reciprocal of the probability of survival as a function of the log of upper-ball stress cycles to failure (Weibull coordinates). For convenience, the ordinate is graduated in statistical percent of specimens failed. A straight line, determined by the method of least squares, is fitted to the experimental data points. From a plot such as this, the number of upper-ball stress cycles necessary to fail any given portion of the specimen group may be obtained.

For comparison, the 10-percent or 50-percent lives on the Weibull plot were used. The 10-percent life is the number of upper-ball stress cycles within which 10 percent of the specimens can be expected to fail; this 10-percent life is equivalent to a 90-percent probability of survival.

Confidence numbers, which indicate the statistical significance of the fatigue life results were calculated by the method of reference 9. A confidence number is the probability, expressed as a percentage, that the difference in life between lot B and the particular lot being considered is real. A confidence number of 95 percent or greater, which is equivalent to the 2σ confidence level (twice the standard deviation), indicates a high degree of certainty.

RESULTS AND DISCUSSION

Fatigue Life Results

As discussed in a previous section, over half of the lot A AMS 5900 balls had visible cracks on the surface. With the remaining balls, which reportedly had no surface cracks, a series of rolling-element fatigue tests were run in the five-ball fatigue tester. The results of this test series with lot A AMS 5900 balls are shown in the Weibull plot of figure 4 and the summary table V.

The 10-percent life of this group of balls was only 2.2 million stress cycles, considerably less than expected and much less than the baseline VIM-VAR AISI M-50 life at identical conditions. As shown in reference 5 and in table V, the VIM-VAR AISI M-50 10-percent life is 8.9 million stress cycles.

Careful examination of the tested balls revealed that some small surface cracks existed on several of the balls thought to be crack free. The balls used in this test series were randomly selected from the group of acceptable balls from the supplier and were randomly oriented in the five-ball test assembly. Fourteen visible cracks were found on the balls of 29 five-ball tests (out of 145 total balls). Five of these cracks coincided with the running tracks of either the upper or the lower balls and spalls formed at all five of them. These were the five shortest lives in the test series.

The remaining spalls in the lot A test series could not be visually related to surface cracks, but the very low lives suggest that subsurface crack or voids may have been present and that these were sites of early fatigue failures. Even if the five shortest lines are omitted from the failure distribution analysis, the 10-percent life is still only 5.4 million stress cycles (dashed line in fig. 4).

Only one of the spalls originating at cracks was on an upper ball (2.5 million stress cycles). To further observe this failure mode, three balls

TABLE V. - FATIGUE TEST RESULTS

[Five ball fatigue tester; 1.27-cm (1/2-in.) diam balls; maximum Hertz stress, 5.52 GPa (800 000 psi); contact angle, 30°; shaft speed, 10 000 rpm; temperature, 339 K (150° F); lubricant, superrefined naphthenic mineral oil.]

Material[a]	Lot	Fatigue life, millions of upper ball stress cycles		Slope	Failure index	Confidence number,[c] percent
		10-percent life	50-percent life		(b)	
AMS 5900	A	2.2.	29.2	0.73	23, 29	< 99
	A[d]	5.4	45.4	.88	18, 24	< 99
	B	73.2	198	1.89	11, 30	---
AMS 5749 (ref. 5)[e]	--	66.4	192	1.77	10, 21	55
AISI M-50 (ref. 5)	--	8.9	36.6	1.33	34, 40	<99

[a]All materials vacumm induction melted, vacuum arc remelted (VIM-VAR).
[b]Number of failures out of total number of tests.
[c]Probability that the observed difference in life between lot B and the lot being considered is real.
[d]Failures at cracks omitted.
[e]Retained austenite, 6.3 vol. %.

were randomly selected from the rejected group of cracked balls and were carefully oriented as upper balls with the cracks crossing approximately perpendicular to the running track. Each of these balls was run at the identical conditions to the fatigue test series until a spall developed at the crack. Spalling occurred in only 32 000, 120 000, and 400 000 cycles on these balls. The crack and the spall that formed at the crack after 120 000 cycles are shown in figure 5.

The 10-percent life of the lot B balls is 73.2 million stress cycles. This is at least 13 times that of the lot A balls. A significant improvement in rolling-element fatigue life is seen with the balls free of surface (and possibly subsurface) cracks.

Warm heading is frequently used for bearing balls somewhat greater than 1.27-cm (1/2-in.) diameter depending on material and manufacturers. It is apparent from this study that AMS 5900 balls of this size and greater must be warm headed to avoid the observed crack problem.

Comparison with AMS 5749 and AISI M-50

The life of the warm headed lot B AMS 5900 balls should be considered more typical of the potential of the material than the lot A balls. Therefore the lot B results are used to compare AMS 5900 with other materials. As seen in table V, the 10 percent life of the lot B AMS 5900 balls is slightly greater than that with AMS 5749 balls tested under identical con-

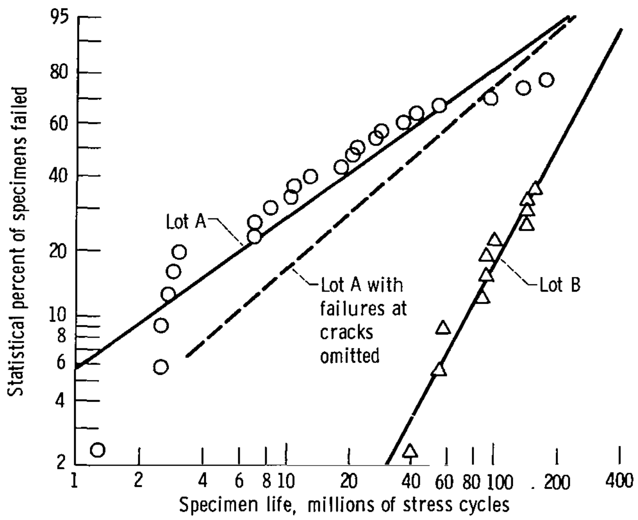
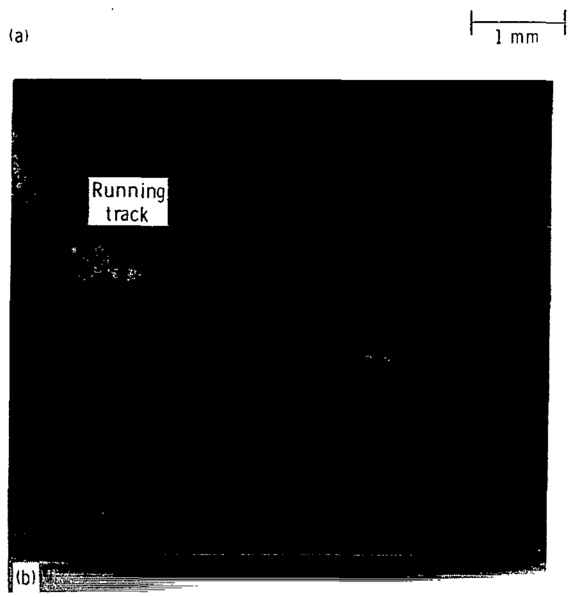


Figure 4. - Rolling-element fatigue life of 12.7-mm (1/2-in.) diameter AMS 5900 balls in five-ball fatigue tester. Maximum Hertz stress, 5.52 GPa (800 000 psi); shaft speed, 10 000 rpm; contact angle, 30°; temperature, 339 K (150° F).



(a) Crack before test.
(b) Spall at crack; after 120 000 stress cycles.

Figure 5. - Fatigue spall originating at surface crack on lot A AMS 5900 ball.

ditions (ref. 5). The difference, however, is statistically insignificant (confidence number, 55 percent), and the two should be considered of equal life. It should be noted that of the AMS 5749 lots tested in reference 5, the AMS 5749 used for comparison here had the lowest level of retained austenite, somewhat higher than, but closest to, that of the AMS 5900 balls. The hardness of the AMS 5749 balls was approximately two points Rockwell C greater than that of the AMS 5900 balls. These differences would tend to favor the AMS 5749. At equal hardness and retained austenite, AMS 5900 may have a slight life advantage over AMS 5749, but the magnitude of the advantage can not be determined from these results.

Also shown in table V are life results from AISI M-50 balls tested under identical conditions (from ref. 5). The 10-percent life of the lot B AMS 5900 balls is over eight times that of the AISI M-50 balls. This difference is statistically significant, since the confidence number is greater than 99 percent.

Both the AMS 5749 and the AISI M-50 balls were VIM-VAR processed. Thus, the AMS 5900 balls, also processed by VIM-VAR, were compared with premium quality materials. The life results for AMS 5900 show that the material has excellent potential as a rolling-element bearing material, having better corrosion resistance than AISI M-50.

SUMMARY OF RESULTS

Rolling-element fatigue tests were run in the five-ball fatigue tester with VIM-VAR AMS 5900 balls made by either cold heading or warm heading. Tests were run at a maximum Hertz stress of 5.52 GPa (800 000 psi), a shaft speed of 10 000 rpm, a contact angle of 30°, and a temperature of 339 K (150° F). A superrefined naphthenic mineral oil was used as the lubricant. The results were compared with results of tests at identical conditions with VIM-VAR AMS 5749 and VIM-VAR AISI M-50. The following results were obtained:

1. The 10-percent life with warm headed AMS 5900 balls was equivalent to that of AMS 5749 and over eight times that of AISI M-50.
2. AMS 5900 balls fabricated by cold heading had small surface cracks which initiated fatigue spalls where these cracks were crossed by running tracks on either upper or lower balls.
3. AMS 5900 balls fabricated by cold heading had a 10-percent life, an order of magnitude less than that of AMS 5900 balls fabricated by warm heading even when cold headed balls with visible surface cracks were omitted from the tests.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, September 1982,
505-32-42

REFERENCES

1. Cunningham, J. S. Jr.; and Morgan, M. A.: Review of Aircraft Bearing Rejection Criteria and Causes. Lubr. Eng., vol. 35, no. 8, Aug. 1979, pp. 435-440.
2. Jones, H. F.: Dicussion to Review of Aircraft Bearing Rejection Criteria and Causes. Lubr. Eng., vol. 35, no. 8, Aug. 1979, p. 441.
3. Johnson, B. L.: A "Stainless High Speed" Steel for Aerospace Applications. Met. Prog., vol. 86, No. 3, 1964, pp. 116-118.
4. Brown, P. F; and Potts, J. R.: Evaluation of Powder Processed Turbine Engine Ball Bearings. Interim Report AFAPL-TR-77-26, Pratt a Whitney Aircraft Group, June 1977. (AD-A046695.)
5. Parker, R. J; and Hodder, R. S.: Rolling-Element Fatigue Life of AMS 5749 Corrosion Resistant, High Temperature Bearing Steel. J. Lub. Technol., vol. 100, no. 2, Apr. 1978, pp. 226-235.
6. Brown, P. F.; Bogardus, G. A.; and Miner, J. R.: Evaluation of Powder Processed Turbine Engine Ball Bearings. AFWAL-TR-80-2110, Pratt a Whitney Aircraft Group, June 1981. (AD-A103263.)
7. Carter, Thomas L.; Zaretsky, Erwin V.; and Anderson, William J.: Effect of Hardness and Other Mechanical Properties on Rolling-Contact Fatigue Life of Four High-Temperature Bearing Steels. NASA TN D-270, 1960.

8. Jones, A. B.: New Departure Engineering Data; Analysis of Stresses and Deflections. vols. 1 and 2. General Motors Corp., 1946.

9. Johnson, L. G.: The Statistical Treatment of Fatigue Experiments. Elsevier Publishing Co., 1964.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TP-2080		
4. Title and Subtitle ROLLING-ELEMENT FATIGUE LIFE OF AMS 5900 BALLS		5. Report Date January 1983 6. Performing Organization Code 502-32-42
7. Author(s) Richard J. Parker		8. Performing Organization Report No. E-1190 10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Paper 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The rolling-element fatigue life of AMS 5900 12.7-mm (1/2-in.) dia was determined in five-ball fatigue testers. The 10-percent life with the warm headed AMS 5900 balls was equivalent to that of AMS 5749 and over eight times that of AISI M-50. AMS balls fabricated by cold heading had small surface cracks which initiated fatigue spalls where these cracks were crossed by running tracks. The cold-headed AMS 5900 balls had a 10-percent fatigue life an order of magnitude less than that of the warm headed balls even when failures on the cold headed balls at visible surface cracks were omitted.

17. Key Words (Suggested by Author(s))		18. Distribution Statement	
Bearings; Bearing life; Rolling-element bearings; Bearing materials		Unclassified - unlimited STAR Category 37	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 12	22. Price* A02

* For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1983

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business
Penalty for Private Use, $300

THIRD-CLASS BULK RATE

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451

U.S.MAIL

2 1 1U,D, 830105 S00903DS
DEPT OF THE AIR FORCE
AF WEAPONS LABORATORY
ATTN: TECHNICAL LIBRARY (SJL)
KIRTLAND AFB NM 87117

NASA

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return