Surface Fatigue Life of M50NiL and AISI 9310 Gears and Rolling-Contact Bars

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Spur gear endurance tests and rolling-element surface fatigue tests were conducted to investigate vacuum-induction-melted, vacuum-arc-remelted (VIM-VAR) M50NiL steel for use as a gear steel in advanced aircraft applications, to determine its endurance characteristics, and to compare the results with those for standard VAR and VIM-VAR AISI 9310 gear material. Tests were conducted with spur gears and rolling-contact bars manufactured from VIM-VAR M50NiL and VAR and VIM-VAR AISI 9310. The gear pitch diameter was 3.5 in. Gear test conditions were an inlet oil temperature of 116°F, an outlet oil temperature of 170°F, a maximum Hertz stress of 248 ksi, and a speed of 10,000 rpm. Bench rolling-element fatigue tests were conducted at ambient temperatures with a bar speed of 12,500 rpm and a maximum Hertz stress of 700 ksi. The VIM-VAR M50NiL gears had a surface fatigue life that was 4.5 and 11.5 times that for VIM-VAR and VAR AISI 9310 gears, respectively. The surface fatigue life of the VIM-VAR M50NiL rolling-contact bars was 13.2 and 21.6 times that for the VIM-VAR and VAR AISI 9310, respectively. The VIM-VAR M50NiL material was shown to have good resistance to fracture through a fatigue spall and to have fatigue life far superior to that of both VIM-VAR and VAR AISI 9310 gears and rolling-contact bars.

Introduction

RECENT developments by aircraft turbine engine groups and others have required the use of fracture-resistant bearing materials for integral rolling-element bearing races. Higher speed bearings require races with good fracture toughness to prevent serious failures after a race fatigue failure (i.e., spall) occurs. The use of advanced high-hot-hardness steels for aircraft engine bearings and aircraft transmissions for helicopters, VSTOL, and geared fans or turboprops has been shown[1,2] to extend the operating life at higher operating temperatures. In addition, the use of high-hot-hardness materials can lengthen operating times considerably if the lubrication and cooling system fails and the operating temperature increases.

Several high-hot-hardness carburizing grade steels have been developed in recent years, and tests with these materials have shown longer surface fatigue lives than standard AISI 9310 gear steel.[3-5] A more recent high-hot-hardness steel, M50NiL, was developed originally as a carburizing-grade race material for rolling-element bearings. It improved fracture toughness while retaining hot hardness and long bearing fatigue life.[6] This material was developed from the standard AISI M50 bearing material by reducing the carbon content to improve the fracture toughness and adding a small amount of nickel to stabilize the austenite and prevent the formation of excessive amounts of ferrite and retained austenite.[6] With its reduced carbon content, the M50NiL material can be case carburized to give a hard bearing surface while retaining a tough core. Rolling-contact (RC) fatigue tests with M50NiL[6] have shown it to have excellent surface fatigue life.

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The objectives of the research reported herein were 1) to investigate M50NiL for use as a gear material, 2) to determine the surface endurance characteristics of M50NiL, and 3) to compare the results with those for standard vacuum-induction-melted, vacuum-arc-remelted (VIM-VAR) and VAR AISI 9310 aircraft gear materials. To accomplish these objectives, tests were conducted with spur gears and RC test bars manufactured from M50NiL. For comparison purposes, spur gears and RC test bars manufactured from VAR and VIM-VAR AISI 9310 were also tested for fatigue life. The gear pitch diameter was 3.5 in. Test conditions for the gears included an inlet oil temperature of 116°F that resulted in an outlet oil temperature of 170°F, a maximum Hertz stress of 248 ksi, and a speed of 10,000 rpm. The rolling-element fatigue tests[6,7] were conducted with 0.375-in.-diam test bars. The RC tests were conducted at ambient temperature with a bar speed of 12,500 rpm and a maximum Hertz stress of 700 ksi.

Apparatus and Procedures

Gear Test Apparatus

The gear fatigue tests were performed in the NASA Lewis Research Center's gear fatigue test apparatus (Fig. 1). This test rig uses the four-square principle of applying the test gear load so that the input drive only needs to overcome the frictional losses in the system. Oil pressure and leakage flow are supplied to the load vanes through a shaft seal. As the oil pressure on the load vanes inside the slave gear is increased, torque is applied to the shaft. This torque is transmitted through the test gears back to the slave gear, where an equal but opposite torque is maintained by the oil pressure. This torque on the test gears, which depends on the hydraulic pressure applied to the load vanes, loads the gear teeth to the desired stress level. The two identical test gears can be started under no load, and the load can be applied gradually without changing the running track on the gear teeth.

Separate lubrication systems are provided for the test gears and the main gearbox. The two lubrication systems are separated at the gearbox shafts by pressurized labyrinth seals. Nitrogen is the seal gas. The test gear lubricant is filtered

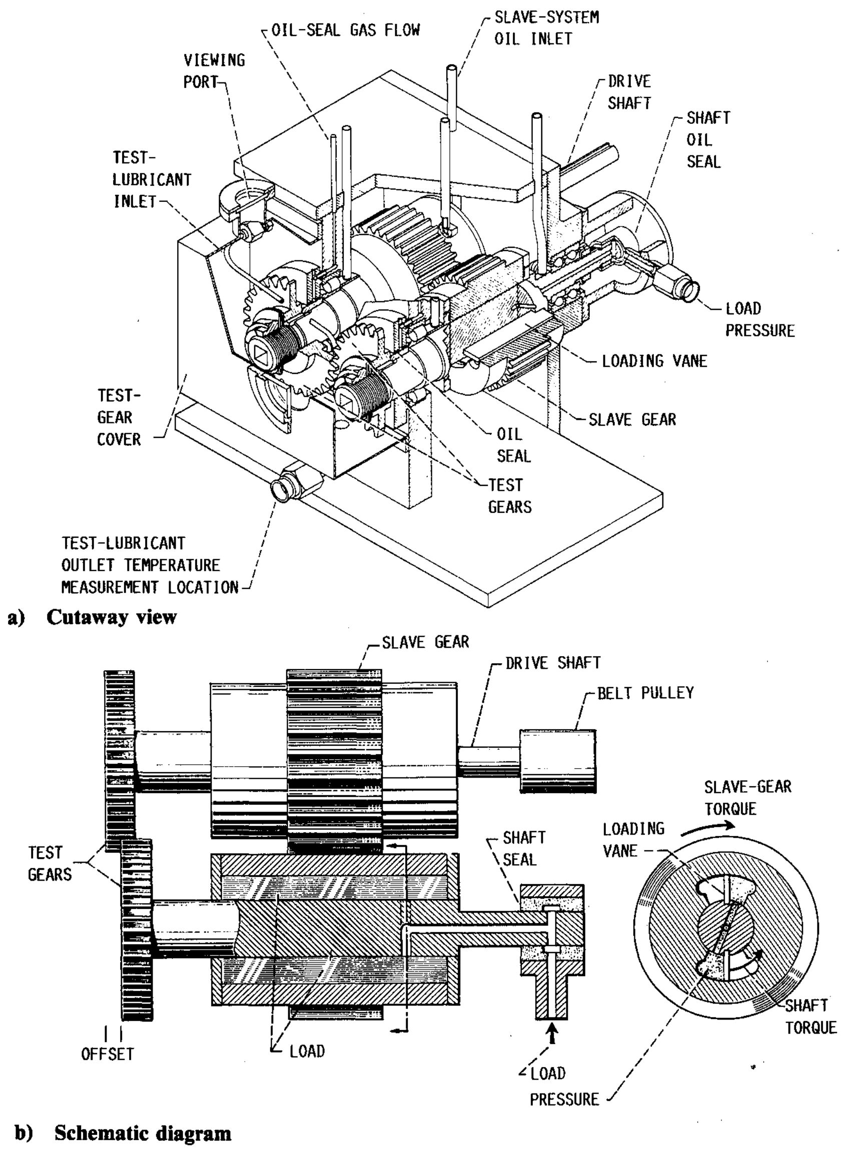


Fig. 1 NASA Lewis Research Center's gear fatigue test apparatus.

through a 5-μm nominal fiberglass filter. The test lubricant can be heated electrically with an immersion heater. The skin temperature of the heater is controlled to prevent overheating the test lubricant.

A vibration transducer mounted on the gearbox is used to automatically shut off the test rig when gear surface fatigue occurs. The gearbox is also automatically shut off if there is a loss of oil flow to either the main gearbox or the test gears, the test gear oil overheats, or there is a loss of seal gas pressurization.

The belt-driven test rig can be operated at several fixed speeds by changing pulleys. The operating speed for the tests reported herein was 10,000 rpm.

Rolling-Contact Fatigue Tester

The RC fatigue tester is shown in Fig. 2. A cylindrical test bar is mounted in the precision chuck. The drive motor attached to the chuck drives the bar, which in turn drives two idler rollers. Load is applied by closing the rollers against the test bar with a micrometer-threaded turnbuckle and a calibrated load cell. Lubrication is supplied by a drop feed system; a needle valve controls the flow rate. Several test runs can be made on one test bar by moving the bar position in the axial direction relative to roller contacts. The test bar rotates at 12,500 rpm and receives 25,000 stress cycles/min. The maximum Hertz stress was 700 ksi.

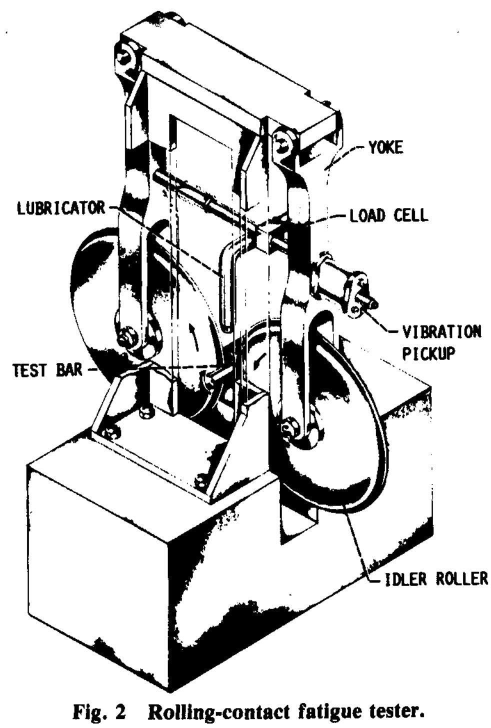


Fig. 2 Rolling-contact fatigue tester.

Test Gears

The dimensions of the gears are given in Table 1. All of the gears had a nominal surface finish on the tooth face of 16 μin. AA. All of the gears had a standard 20-deg involute profile with tip relief. The tip relief was 0.0005 in. starting at the highest point of single-tooth contact.

Rolling-Contact Test Bar Specimen

The test specimens for the RC fatigue tester were cylindrical bars 3.0 in. long with a 0.375-in. diam. The surface finish was 5–8 μin. AA.

The large matting rollers had a diameter of 7.5 in. and a crown radius of 0.250 in. The surface finish of the rollers was the same as that of the test bars.

Test Materials

The 9310 test gears and RC bars were manufactured from either VAR, consumable-electrode vacuum-melted (CVM), or VIM-VAR AISI 9310.

The M50NiL test gears and RC bars were manufactured from VIM-VAR material. This M50NiL material was developed from a standard AISI M50 by reducing the carbon content from 0.85 to 0.13 to provide improved fracture toughness and by adding a small amount of nickel (3.4%) to stabilize the austenite and prevent the formation of excessive amounts of ferrite and retained austenite.

The chemical composition of the test gears and RC bars is given in Table 2. The heat treatment procedure for the gears and RC bars is given in Table 3. The gears and RC bars were case carburized and hardened to the case and core properties shown in Table 4. Cross sections of an AISI and M50NiL gear tooth are shown in Figs. 3a-3c. The case and core photomicrographs of the 9310 and M50NiL are shown in Figs. 4a-4d. The retained austenite shown for the M50NiL is much higher than would be expected for the treatment procedure specified in Table 3. This high level of retained austenite apparently was the result of missing the deep-freeze treatment. This was further verified when the used gear was given a deep freeze at −100°F and double temper at 975°F. The retained austenite

Table 1 Gear data (gear tolerance per AGMA class 12)

Number of teeth	28
Diametral pitch	8
Circular pitch, in.	0.3927
Whole depth, in.	0.300
Addendum, in.	0.125
Chordal tooth thickness reference, in.	0.191
Pressure angle, deg	20
Pitch diameter, in.	3.500
Outside diameter, in.	3.750
Root fillet, in.	0.04–0.06
Measurement over pins, in.	3.7807–3.7915
Pin diameter, in.	0.216
Backlash reference, in.	0.010
Tip relief, in.	0.0005
Tooth width, in.	0.25

Table 2 Chemical composition of test materials

Element	AISI 9310 Gears	AISI 9310 RC bars	M50NiL Gear	M50NiL RC bars (nominal)
	Composition, wt %			
Carbon				
Core	0.11	0.11	0.13	0.11–0.15
Case	0.81	0.81	0.86	0.86
Manganese	0.58	0.69	0.28	—
Phosphorus	0.003	0.005	0.002	—
Sulfur	0.004	0.002	0.002	—
Silicon	0.26	0.30	0.18	—
Copper	0.21	0.07	0.05	—
Chromium	1.38	0.24	4.21	4.0–4.25
Molybdenum	0.13	0.11	4.30	4.0–4.5
Vanadium	—	—	1.19	1.13–1.33
Nickel	3.20	3.19	3.44	3.20–3.60
Cobalt	—	—	0.01	—
Iron	Balance	Balance	Balance	—

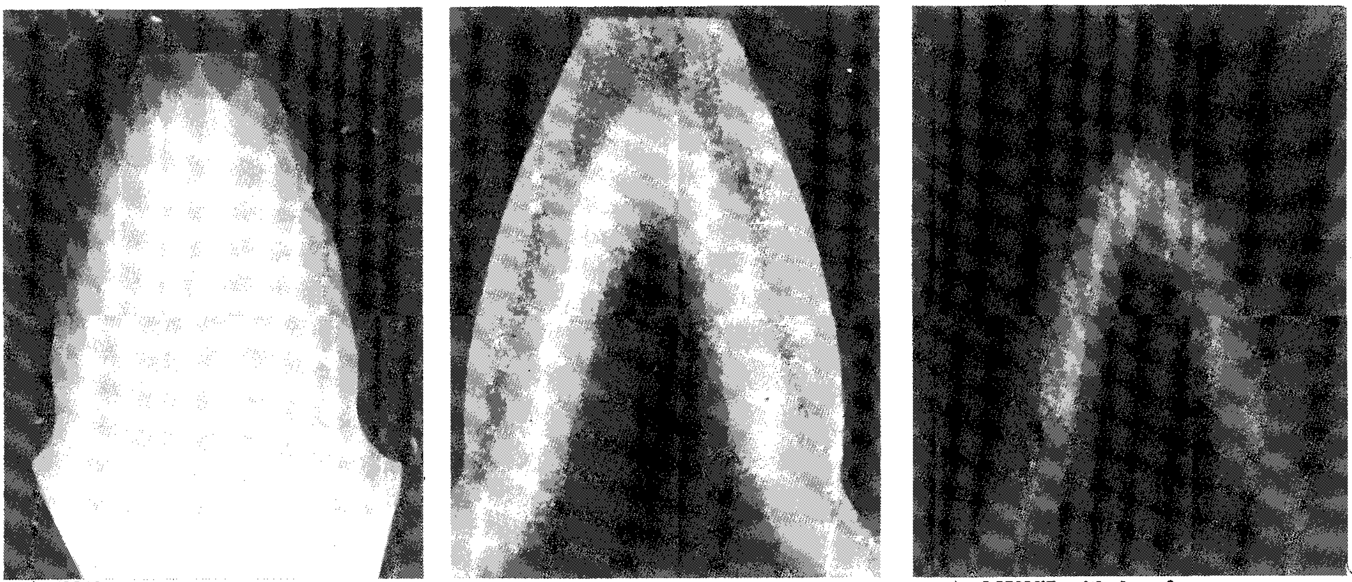
Table 3 Heat treatment procedure for materials tested

		AISI 9310				M50NiL			
		Gears		RC bars		Gears		RC bars	
Step	Process	Temperature, °F	Time, h	Temperature, °F	Time, h	Temperature, °F	Time, h	Temperature, °F	Time, h
1	Preoxidation	—	—	—	—	1750	2[a]	1750	2[a]
2	Carburizing	1650	8	1775	12	1750	—	1750	12[b], 12[c]
3	Tempering	1200	10	1100	10	1200	2	[d]	—
4	Preheating	—	—	—	—	1500	—	—	—
5	Austenizing or hardening	1500	2.5	1575	0.4	2025	0.25	2025	15
6	Quenching	—	—	—	—	1100	0.2	1100	10
7	Tempering	—	—	—	—	975	2	957	2
8	Deep freezing	−120	—	−100	—	−100	1[e]	−100	1
9	Tempering	350	2	360	1	975	2 + 2	975	2

[a]Air. [b]At 0.7 carbon potential. [c]At 0.6 carbon potential. [d]Oil quench. [e]Omitted by error.

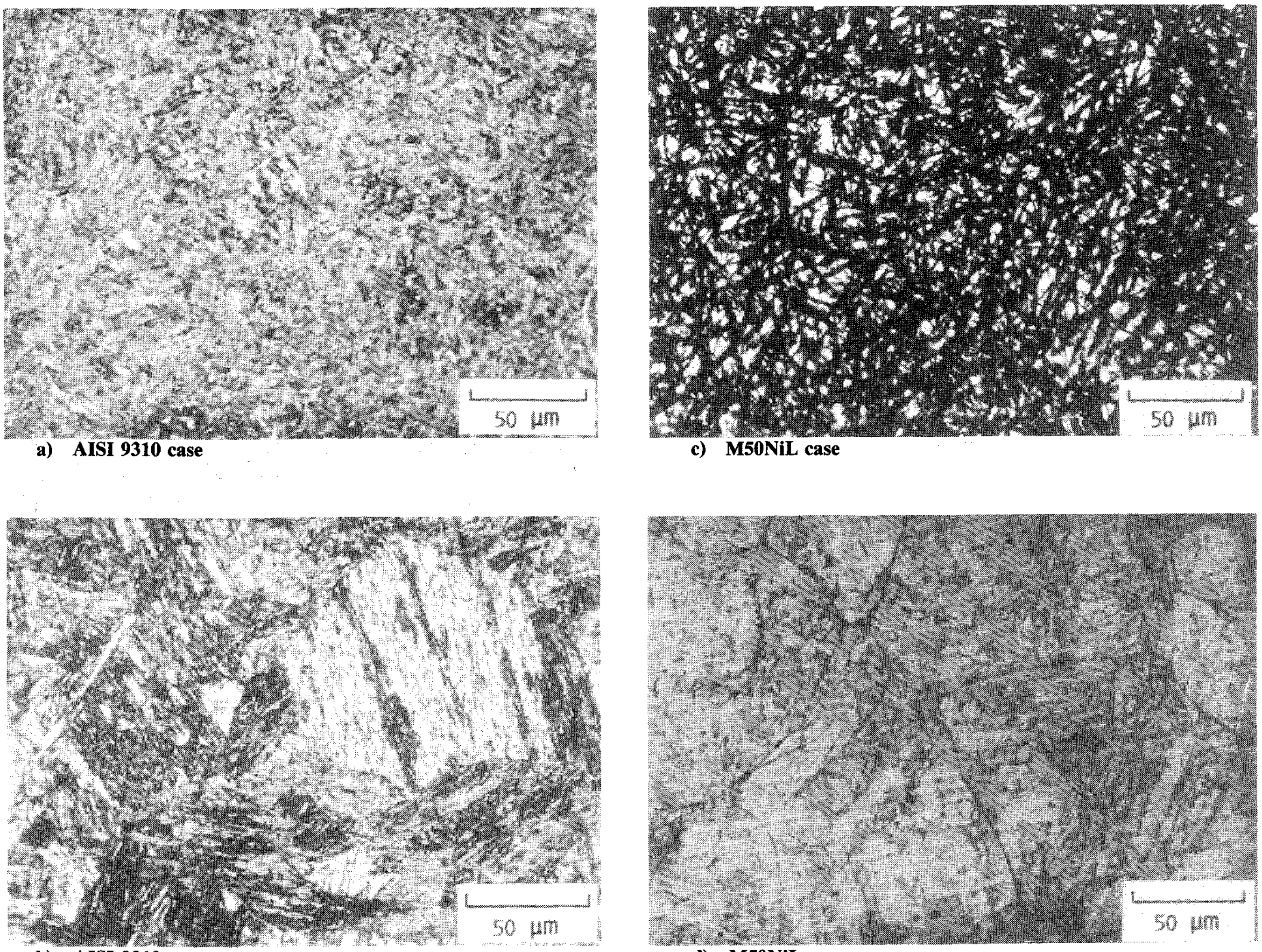
Table 4 Metallurgical case and core characteristics of test specimens

Material	Effective case depth at Rockwell C 50, in.	Rockwell C hardness Case	Rockwell C hardness Core	Case retained austenite, vol %	Grain size Case	Grain size Core	Fracture toughness Room temperature ksi, in.	Fracture toughness 400°F ksi, in.
AISI 9310								
Gears	0.032	61.0	38	10.0	—	—	85	—
RC bars	0.033	61.4	38	11.2				
M50NiL								
Gears	0.075	60.6	48	46.0			48	108
RC bars	0.080	64.0	45	8.0	>7	5–7		



a) 9310 **b) M50NiL with no deep freeze** **c) M50NiL with deep freeze**

Fig. 3 Cross sections through AISI 9310 and M50NiL with and without 200 K (−100°F) deep freeze.



a) AISI 9310 case **c) M50NiL case**

b) AISI 9310 core **d) M50NiL case**

Fig. 4 Case and core microphotographs of AISI 9310 and M50NiL test samples.

was then found to be 5%. A cross section through an M50NiL gear tooth after the deep freeze and temper is shown in Fig. 3c. In addition, the hardness increased approximately 2 points Rockwell C, as shown in Fig. 5. It was not expected that the absence of the deep freeze would change the fatigue life of the M50NiL gears significantly.

Lubricant

All the gears were lubricated with a single batch of synthetic paraffinic oil, which was the standard test lubricant for the gear tests. The physical properties of this lubricant are summarized in Table 5. Five vol % of an extreme-pressure additive designated Lubrizol 5002 (partial chemical analysis given in Table 5) was added to the lubricant.

The RC test specimens were lubricated with a standard diester test lubricant that met the MIL-L-7808G specification. The fluid was a mixture of two base stocks, a diester plus a (trimethylol propane) polyester. The additives in this fluid included antioxidants, load-carrying additives, metal passivators, a hydrolytic stability additive, and a silicone antifoam additive. The types and levels of the additives are proprietary. The lubricant properties are given in Table 5.

Test Procedure

Gears

After the test gears were cleaned to remove their protective coating, they were assembled on the test rig. The test gears ran in an offset condition with a 0.120-in. tooth-surface overlap to give a load surface on the gear face of 0.110 in., allowing for an edge radius on the gear teeth. Since the offset test method may introduce edge loading effects, the method was checked originally with both crowned and uncrowned gears. There was no difference between the crowned and uncrowned gears; also, all fatigue spalls with uncrowned gears originated evenly along the tooth flank and never started at the edge location. This is proof that the offset test condition is an acceptable method for surface fatigue testing.

If both faces of the gears were tested, four fatigue tests could be run for each set of gears. All tests were run in at a load per unit length of 700 lb/in. for 1 h. The load was then increased to 3300 lb/in., which resulted in a pitchline maximum Hertz stress of 248 ksi. At the pitchline load, the tooth bending stress was 30 ksi if plain bending was assumed. However, because there was an offset load, an additional stress was imposed on the tooth bending stress. Combining the bending and torsional moments gave a maximum stress of 37 ksi. This bending stress did not include the effects of tip relief, which would also increase the bending stress.

Operating the test gears at 10,000 rpm gave a pitchline velocity of 9163 ft/min. Lubricant was suplied to the inlet mesh at 49 in.^{3}/min and 116 ± 10°F. The lubricant outlet temperature was nearly constant at 170 ± 5°F. The tests ran continuously (24 h/day) until the rig was automatically shut down by the vibration detection transducer (located on the gearbox adjacent to the test gears) or until 500 h of operation without failure were completed. The lubricant circulated through a 5-μm fiberglass filter to remove wear particles. For each test, 1 gal of lubricant was used. At the end of each test, the lubricant and the filter element were discarded. Inlet and outlet oil temperatures were recorded continuously on a strip-chart recorder.

The pitchline elastohydrodynamic (EHD) film thickness was calculated by the method of Dowson and Higginson.[8] It was assumed, for this film thickness calculation, that the gear temperature at the pitch line was equal to the outlet oil temperature and that the inlet oil temperature to the contact zone was equal to the gear surface temperature, even though the inlet oil temperature was considerably lower. It is possible that the gear surface temperature was even higher than the outlet oil temperature, especially at the end points of sliding contact. The EHD film thickness for these conditions was computed to be 13 μin., which gave an initial ratio of film thickness to composite surface roughness h/σ of 0.55 at the 248-ksi pitchline maximum Hertz stress.

Each running surface on a pair of gears was considered as a system and, hence, a single test. Test results were evaluated by using Weibull plots calculated by the method of Johnson.[9] (A Weibull plot is the number of stress cycles vs the statistical percentage of gear systems failed.) Since the gears were run in an offset condition, four tests were obtained from each pair of gears.

Rolling-Contact Tests

Fatigue testing was also performed in the RC rig. The test bar was installed and the rollers were brought against the bar by using the turnbuckle. The load applied was sufficient to allow the bar to drive the contacting rollers, and the bar was accelerated to the 12,500-rpm test speed.

When the rollers and the test bar were in thermal equilibrium at a bar temperature of 90°F, the full load of 281 lb was applied to give the test bar a maximum Hertz stress of 700 ksi. When a fatigue failure occurred, the rig and related instrumentation were automatically shut down by a vibration detection system. The axial position of the test bar in the drive chuck was changed to a new running track before testing was resumed. Test results were also evaluated according to the methods of Johnson.[9] The end film thickness for this condition was 8.3 μin., which gave an h/σ of 0.75 at the 700 ksi maximum Hertz stress.

Results and Discussion

Gear Life Results

One lot of each VAR AISI 9310, VIM-VAR AISI 9310, and VIM-VAR M50NiL spur gears was endurance tested. Test conditions were a tangential load of 3305 lb/in., which produced a maximum Hertz stress of 248 ksi and a speed of 10,000 rpm. The gears failed by classical subsurface pitting fatigue. The pitting fatigue life results of these tests are shown in the Weibull plots of Fig. 6 and are summarized in Table 6. These data were analyzed by the method of Johnson.[9]

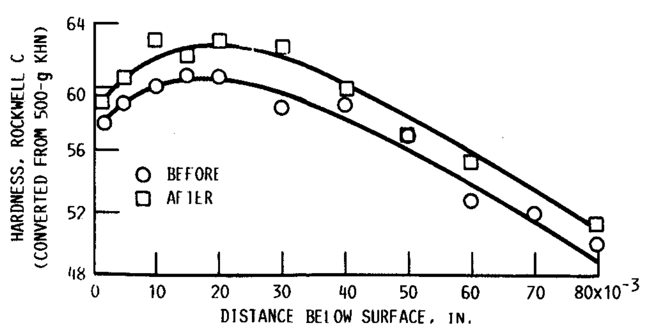


Fig. 5 Hardness of VIM-VAR M50NiL gear tooth before and after one deep freeze and temper cycle.

Table 5 Lubricant properties

Property	Synthetic paraffinic oil plus additives[a]
Kinematic viscosity, cS at	
−20°F	2500
100°F	31.6
210°F	5.5
400°F	2.0
Flashpoint, °F	455
Firepoint, °F	500
Pour point, °F	−65
Specific gravity	0.8285
Vapor pressure at 100°F, Torr	0.1
Specific heat at 100°F, Btu/lb °F	0.523

[a]EP additives: Lubrizol 5002 (5 vol %) containing 0.03 vol % phosphorus and 0.93 vol % sulfur.

Table 6 Fatigue life results for test gears and rolling-contact bars

Material	System life, millions of stress cycles 10%	10%	Weibull slope	Failure index	Confidence number at 10% life level, %[a]
Gears					
VAR AISI 9310	18.8	46	2.1	18 out of 19	—
VIM-VAR AISI 9310	48	200	1.3	24 out of 33	92.5
VIM-VAR M50NiL	217	496	2.3	2 out of 20	99
Rolling-contact bars					
VAR AISI 9310	4.2	9.4	2.3	10 out of 10	—
VIM-VAR AISI 9310	6.84	15.74	2.26	10 out of 10	76
VIM-VAR M50NiL	90.6	219	2.1	5 out of 20	99

[a]Percentage of time that the 10% life obtained with VAR AISI 9310 will have the same relation to the 10% life obtained with VIM-VAR AISI 9310 or VIM-VAR M50NiL.

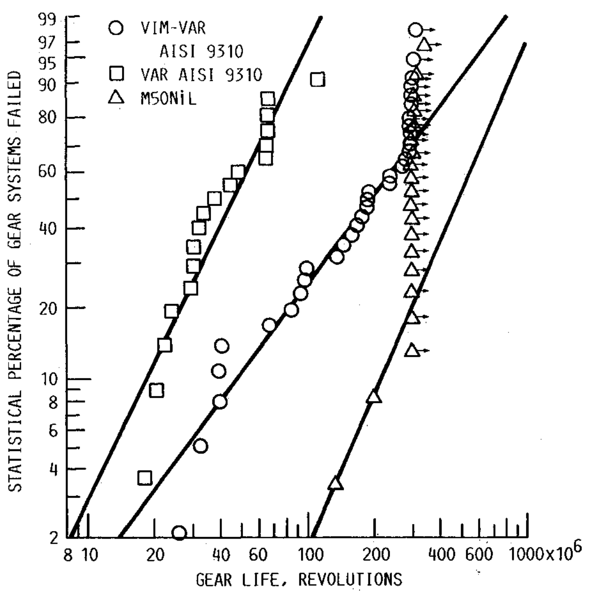
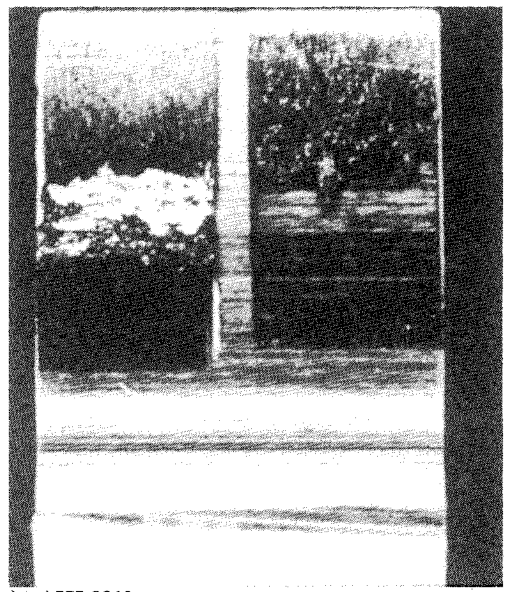


Fig. 6 Surface fatigue life of VAR and VIM-VAR AISI 9310 and M50NiL test gears: Speed = 10,000 rpm; maximum Hertz stress = 248 ksi; temperature = 170°F; lubricant = synthetic paraffin with 5 vol % Lubrizol 5002 (EP additive). Arrows denote suspension of tests.

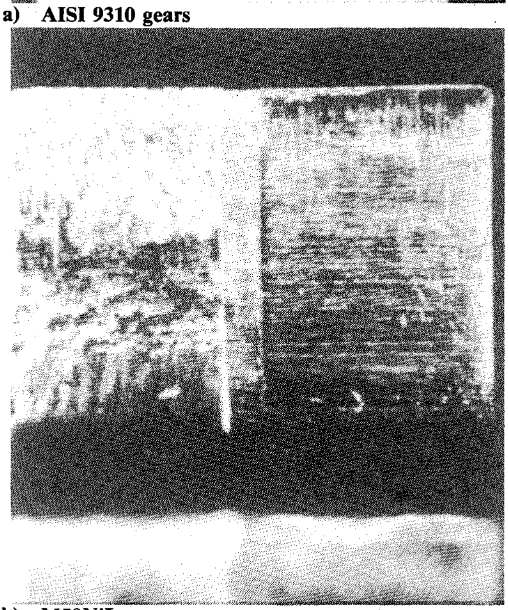
The VAR AISI 9310 material exhibited 10 and 50% pitting fatigue lives of 18.8 and 46 × 10^6 stress cycles, respectively. The failure index (i.e., the number of fatigue failures out of the number of sets tested) was 18 out of 19. A typical fatigue spall that occurred near the pitch line is shown in Fig. 7a. This spall is similar to those observed in rolling-element fatigue tests. The pitchline pitting is the result of high subsurface shearing stress, which develops subsurface cracks. These subsurface cracks propagate into a crack network and result in a fatigue spall that is slightly below the pitch line, where the Hertz stress is very high from single-tooth contact and where some sliding conditions exist.

Pitting fatigue life results of the gears made from VIM-VAR AIS 9310 material are also shown in Fig. 6. The 10 and 50% surface fatigue lives were 48 and 200 × 10^6 stress cycles, respectively. The failure index was 24 out of 33. Nine suspensions did not fail after completing 500 h of testing. The 10% life of the VIM-VAR AISI 9310 was more than two times, and the 50% life more than four times that of the VAR material. The confidence number for the 10% life level was 92.5%, which indicates that the difference is statistically significant. (The confidence number indicates the percentage of time the relative lives of the material will occur in the same order.) These data indicate that for longer life the use of VIM-VAR AISI 9310 steel is preferred over VAR AISI 9310 steel.

The pitting fatigue life results of the gears made from VIM-VAR M50NiL material are also shown in Fig. 6. The 10 and 50% surface fatigue lives were 217 and 496 × 10^6 stress cycles, respectively. The failure index was 2 out of 20. Eighteen suspensions ran 500 h without failure. A typical fatigue spell for the VIM-VAR M50NiL gear is shown in Fig. 7b. Some of the M50NiL gears were deliberately run with a surface fatigue spall for up to 12 additional hours without a tooth fracture oc-



a) AISI 9310 gears



b) M50NiL gears

Fig. 7 Typical fatigue spall of AISI 9310 and M50NiL test gears: Speed = 10,000 rpm; maximum Hertz stress = 248 ksi; temperature = 170°F; lubricant = synthetic paraffin with 5 vol % Lubrizol 5002 (EP additive).

curring. This indicated that the M50NiL had a good fracture toughness since no tooth fractures occurred even though gears were run with fatigue spalls and thus increased dynamic loads. The 10% surface fatigue life of the VIM-VAR M50NiL was more than 11 times that of the VAR AISI 9310 and more than 4 times that of the VIM-VAR AISI 9310. The confidence numbers for the M50NiL were 99% compared with the VAR 9310 and 92.5% compared to the VIM-VAR 9310, both of which are statistically significant.

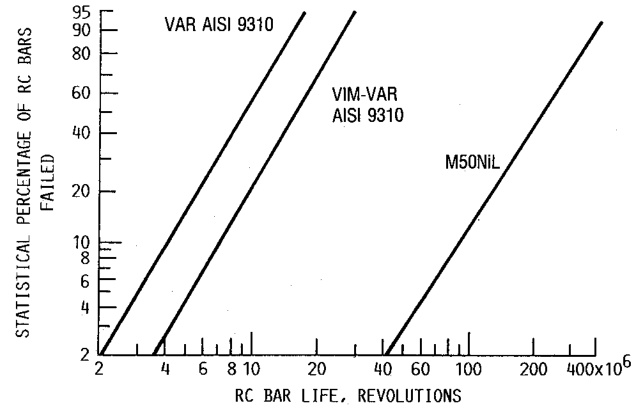


Fig. 8 Rolling-contact fatigue life of VAR and VIM-VAR AISI 9310 and M50NiL in rolling-contact fatigue tester: Maximum Hertz stress = 700 ksi; bar speed = 12,500 rpm; temperature = ambient; lubricant = MIL-L-7808G.

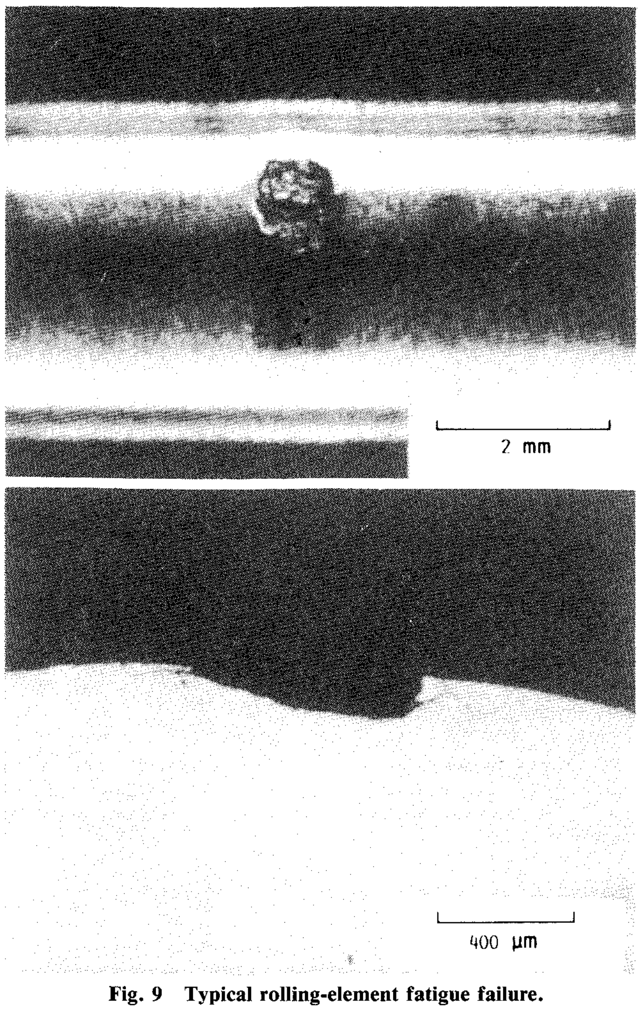


Fig. 9 Typical rolling-element fatigue failure.

Rolling-Element Life Results

Test bars of VAR AISI 9310, VIM-VAR AISI 9310, and VIM-VAR M50NiL were tested in the RC fatigue tester shown in Fig. 2. The test data were originally reported in Refs. 6 and 7. One lot of each material was tested. The RC bars were tested at a maximum Hertz stress of 700 ksi and a bar speed of 12,500 rpm. The RC tests were run at ambient temperature (no external heat source) with a MIL-L-7808G lubricant. The results of these tests are shown in the Weibull plots of Fig. 8 and are summarized in Table 6. These data were analyzed by the method of Johnson.[9] A typical surface fatigue spall for an RC test specimen is shown in Fig. 9.

The VAR AISI 9310 RC test bars exhibited 10 and 50% pitting fatigue lives of 4.2 and 9.4 $\times$ 10^6 stress cycles, respectively. The failure index was 10 out of 10.

The VIM-VAR AISI 9310 RC test bars had 10 and 50% pitting fatigue lives of 6.84 and 15.74 $\times$ 10^6 stress cycles, respectively. The failure index was 10 out of 10. The confidence number for the difference in the 10% lives of the VAR and VIM-VAR 9310 test bars was 76%. Although this is low, it is still considered statistically significant.

The VIM-VAR M50NiL RC test bars had 10 and 50% pitting fatigue lives of 90.6 and 219 $\times$ 10^6 stress cycles, respectively. The failure index was 5 out of 20. The confidence number for the difference in life between the M50NiL bars and the VAR and VIM-VAR AISI 9310 was 99%, a statistically significant difference.

From the results of the data for the gear tests and the RC test bars for VAR AISI 9310, VIM-VAR AISI 9310, and VIM-VAR M50NiL, it is concluded that the VIM-VAR 9310 material is superior to the VAR material for surface fatigue life. This conclusion was not unexpected since a cleaner steel would have fewer inclusions, where fatigue spalls tend to originate, and, therefore, longer fatigue life.

VIM-VAR M50NiL was shown to be far superior in life to either VAR or VIM-VAR AISI 9310, being 4.5 times the VIM-VAR 9310 for gears and 13.2 times the VIM-VAR 9310 for RC bars and 11.5 times the VAR 9310 for gears and 21.6 times the VAR 9310 for RC bars. These life differences are very large and indicate that the VIM-VAR M50NiL offers a significant advantge as a gear material over VIM-VAR AISI 9310. In addition, the VIM-VAR M50NiL gear material exhibited good fracture toughness and, thus, is very attractive as a gear material. The higher temperature capability of the M50NiL, i.e., 600°F, also enhances this material for gear applications where this requirement is needed, such as high-speed aircraft and aircraft that must operate for up to 1 h after loss of lubricant.

Summary of Results

Spur gear endurance tests and rolling-element surface tests were conducted to investigate VIM-VAR M50NiL steel for use as a gear steel in advanced aircraft applications, to determine its endurance characteristics, and to compare the results with those for standard VAR and VIM-VAR AISI 9310 gear material. Tests were conducted with spur gears and RC bars manufactured from VIM-VAR M50NiL and VAR and VIM-VAR AISI 9310. The gear pitch diameter was 3.5 in. Gear test conditions were an inlet oil temperature of 116°F, an outlet oil temperature of 170°F, a maximum Hertz stress of 248 ksi, and a speed of 10,000 rpm. Bench rolling-element fatigue tests were conducted at ambient temperature with a bar speed of 12,500 rpm and a maximum Hertz stress of 700 ksi.

The following results were obtained:

1) The VIM-VAR M50NiL test gears had a 10% surface fatigue life that was 4.5 times that of the VIM-VAR AISI 9310 and 11.5 times that of the VAR AISI 9310 material.

2) The VIM-VAR M50NiL RC test bars had a 10% surface fatigue life that was 13.2 times that of the VIM-VAR AISI 9310 and 21.6 times that of the VAR AISI 9310 material.

3) The VIM-VAR M50NiL was shown to have good resistance to fracture through a fatigue spall in a gear tooth and to

have fatigue life far superior to that of VAR and VIM-VAR AISI 9310 in both gear and RC bar tests.

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