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PITTING FATIGUE CHARACTERISTICS OF AISI M-50 AND SUPER NITRALLOY SPUR GEARS

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SUMMARY

Two groups of 8.89-centimeter- (3.50-in.-) pitch-diameter spur gears, without tip relief, made from consumable-electrode vacuum-melted (CVM) AISI M-50 steel and CVM Super Nitralloy (5Ni-2Al) were tested under conditions which produced fatigue pitting. The Rockwell C hardness of the M-50 material was 62 and that of Super Nitralloy was 61.5. Test conditions included a speed of 10 000 rpm, a maximum Hertz stress of 190×10^7 newtons per square meter (275 000 psi) at the gear pitch line, and lubrication with a super-refined, naphthenic mineral oil having an additive package.

At a 90-percent probability of survival, the M-50 gears had fatigue lives approximately 50 percent longer than the Super Nitralloy gears. However, the difference in life was not considered statistically significant. Both groups of gears failed from classical rolling-element fatigue at the pitch circle. That is, the gear teeth failed because of spalling which appeared to originate from subsurface initiated cracks. The spall was limited in area and depth of penetration. Spalled M-50 gears that were deliberately overrun failed because of fatigue fracture within 2 hours after spalling had occurred. Under the same conditions, gears made from the Super Nitralloy material did not fracture.

Wear measurements across the gear teeth indicated that more wear occurred with the M-50 material than with the Super Nitralloy material. However, the difference in wear was not considered significant.

INTRODUCTION

Present emphasis on heavy-lift, vertical-takeoff-and-landing (VTOL) and short-takeoff-and-landing (STOL) type aircraft is demanding improved power densities for gearboxes. This means high gear loading and increased speed capability with lighter gears. At the same time, increased temperature requirements will make it more difficult to operate the gears at these more severe conditions.

One of the limitations of gear technology that prevent meeting the improved requirements is a lack of knowledge relating to gear materials that are notch insensitive and have increased surface load carrying capacity. Gear teeth will fail because of tooth breakage and surface distress in addition to rolling-element fatigue. Increased gear-tooth loading will, of course, aggravate these problems.

Much tooth bending endurance testing has been performed on gears over a period of several decades; the results of such tests (ref. 1), however, have not been definitive. Results obtained in rolling-element fatigue tests (ref. 2) show that the following parameters can significantly affect fatigue life: material hardness, material heat treatment, lubricant type and batch, temperature, surface finish, operating speed, and contact stress. Unfortunately, these variables have not been carefully controlled (or have not been controlled at all) in gear testing. In some instances, insufficient tests were performed whereby the conclusions derived from these tests were statistically inconclusive. Furthermore, some tooth bending fatigue tests which have been performed (ref. 3) have been more a case of fretting fatigue, wherein tooth fracture occurs at the incipient spall caused by the fretting.

An advanced material which has been used in aircraft gear applications is Super Nitralloy (5Ni-2Al). This material has shown good gear load carrying capacity (ref. 1). This material is similar to Nitralloy N except for the addition of 2 percent nickel and 1 percent aluminum to give it better hot hardness capability and better nitriding capability. The Nitralloy N material has been used for aircraft gears and splines for many years and was used for high temperature lubricant testing in references 4 and 5. Bending fatigue tests (ref. 1) of Super Nitralloy (5Ni-2Al) gear teeth indicate that this material has very good strength properties at temperatures to 644 K (700° F).

Another material which has wide acceptance in aircraft applications for moderate to high temperatures is AISI M-50 steel (ref. 6). This material has been used mainly as a bearing steel. However, there has been limited application of this material for gears in aircraft accessory gear boxes. This material has an operating temperature potential (ref. 7) in excess of 589 K (600° F).

The objective of the research reported herein was to compare under closely controlled test conditions the fatigue lives and failure modes of test spur gears made of Super Nitralloy (5Ni-2Al) and of AISI M-50 steel.

In order to accomplish these objectives, tests were conducted with groups of 8.89-centimeter- (3.5-in.-) pitch-diameter spur gears made of consumable-electrode vacuum-melted (CVM) Super Nitralloy (5Ni-2Al) and CVM AISI M-50 steel, at a temperature of 350 K (170° F), a maximum contact (Hertz) stress of 190×10^7 newtons per square meter (275 000 psi), and at a speed of 10 000 rpm. All experimental results were obtained with a super-refined, naphthenic mineral oil having a proprietary additive package (from one lubricant batch) plus a 5-percent antiwear additive. All gears of each material were manufactured from a single lot of that material.

APPARATUS, SPECIMENS, AND PROCEDURE

Gear Test Apparatus

The gear fatigue tests were performed in the NASA Lewis Research Center's gear test apparatus, shown in figure 1. This test rig uses the four-square principle of applying the test gear load so that the input drive need only overcome the frictional losses in the system.

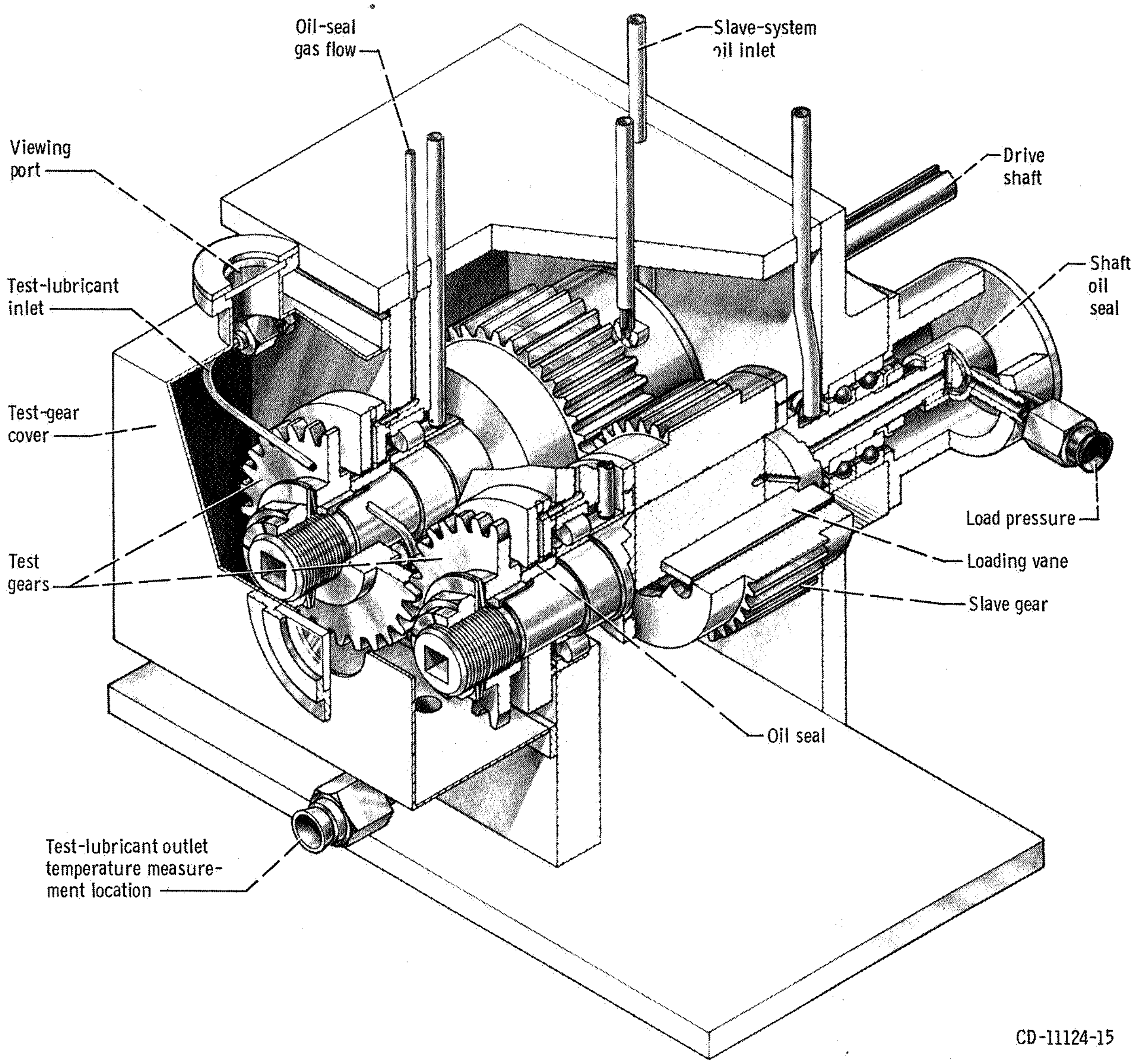
A schematic of the test rig is shown in figure 1(b). Oil pressure and leakage flow is supplied to the load vanes through a shaft seal. As the oil pressure is increased on the load vanes inside the slave gear, torque is applied to the shaft. This torque is transmitted through the test gears back to the slave gear, where an equal but opposite torque is maintained on the slave gear 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 lubricant systems are separated at the gearbox shafts by pressurized labyrinth seals. Nitrogen was used as the seal gas.

The fluid used for the main gearbox lubrication and for the hydraulic system is filtered through a 30-micrometer filter and is water cooled to 297 K (75° F). Hydraulic pressure up to 690×10^{4} newtons per square meter (1000 psi) can be supplied to the load actuator to give a gear tooth maximum load capability of 6672 newtons (1500 lb). The test gear lubricant is filtered through a 5-micrometer fiber-glass filter. The test lubricant can be heated electrically with an immersion heater to a maximum of 589 K (600° F). The skin temperature of the heater is controlled to prevent overheating of the test lubricant.

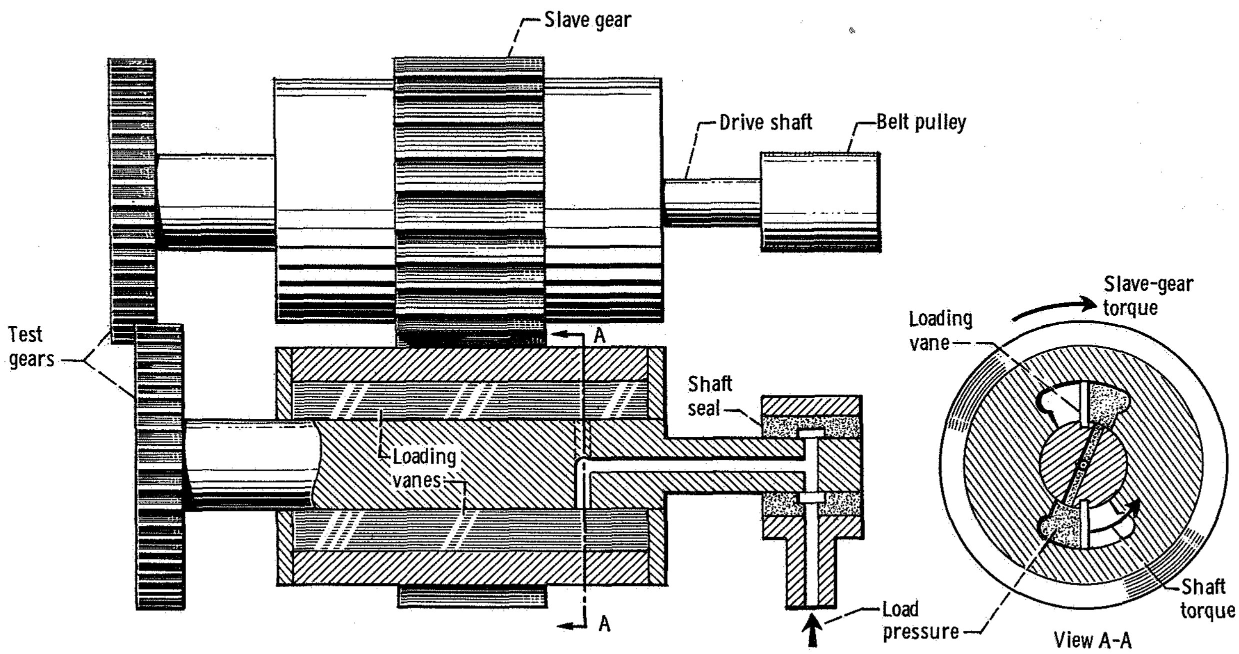
A vibration transducer is mounted on the gearbox, adjacent to the test gears, and is used to automatically shut off the test rig when a gear-surface fatigue failure occurs. The gearbox is also automatically shut off if there is a loss of oil flow to either the main gearbox or to the test gears, if the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

The test rig is belt driven with a 18 650-watt (25-hp) motor and can be operated at several fixed speeds by changing pulleys. The operating speed for the tests reported herein was 10 000 rpm.



(a) Cutaway view.

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



(b) Schematic diagram.

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Figure 1. - Concluded.

Test Lubricant

All tests were conducted with a single batch of super-refined naphthenic mineral-oil lubricant having proprietary additives (antiwear, antioxidant, and antifoam). The physical properties of this lubricant are summarized in table I. Five percent of an extreme-pressure additive, designated Anglamol 81, with a chemical analysis as given in table II, was added to the lubricant. Lubricant flow rate was held constant at 800 cubic centimeters per minute, and lubrication was supplied to the inlet mesh of the gear set by jet lubrication. The lubricant inlet temperature was constant at 319±6 K ($115^{\circ}\pm10^{\circ}$ F), and the lubricant outlet temperature was nearly constant at 350±3 K ($170^{\circ}\pm5^{\circ}$ F). This outlet temperature was measured at the outlet of the test-gear cover. A nitrogen cover gas was used throughout the test as a base-line condition which allowed testing at the same conditions at much higher temperatures without oil degradation. This cover gas also reduced the effect of the additives on the gear surface boundary lubrication by reducing the chemical reactivity of the additive-metal system by excluding oxygen.

TABLE I. - PROPERTIES OF SUPER-REFINED, NAPHTHENIC, MINERAL-OIL TEST LUBRICANT

Kinematic viscosity, cm^2/sec (cS), at	
266 K (20° F)	2812×10^{-2} (2812)
311 K (100° F)	73×10^{-2} (73)
372 K (210° F)	7.7×10^{-2} (7.7)
477 K (400° F)	1.6×10^{-2} (1.6)
Flash point, K ($^\circ$F)	489 (420)
Autoignition temperature, K ($^\circ$F)	664 (735)
Pour point, K ($^\circ$F)	236 (-35)
Density at 289 K (60° F), g/cm^3	0.8899
Vapor pressure at 311 K (100° F), mm Hg (or torr)	0.01
Thermal conductivity at 311 K (100° F), J/(m)(sec)(K) (Btu/(hr)(ft)($^\circ$F))	0.04 (0.0725)
Specific heat at 311 K (100° F), J/(kg)(K) (Btu/(lb)($^\circ$F))	582 (0.450)

TABLE II. - PROPERTIES OF LUBRICANT ADDITIVE ANGLAMOL 81

Percent phosphorous by weight	0.66
Percent sulfur by weight	13.41
Specific gravity	0.982
Kinematic viscosity at 372 K (210° F), cm^2/sec (cS)	29.5×10^{-2} (29.5)

Test Gears and Materials

The test gears used in the tests reported herein are shown in figure 2. Dimensions for the test gears are shown in figure 3 and are summarized in table III. All gears had a nominal surface finish on the tooth face of 0.406 micrometer rms (16 μin. rms) and a standard 20° involute tooth profile without tip relief.

The test gears were manufactured from two materials. These were CVM Super Nitralloy (5Ni-2Al) and CVM AISI M-50 steel. The chemical compositions of these materials are given in table IV.

The gears manufactured from the CVM AISI M-50 material were through-hardened to a Rockwell C hardness of 62±1 in accordance with the heat-treatment schedule of table V. Figure 4 is a photomicrograph of an etched and polished surface showing the microstructure of the AISI M-50 material. The carbide cluster apparent in the micrograph indicates that the M-50 material perhaps was not worked enough to break up the carbide formations. A condition such as this may have some adverse effect on fatigue life.

The gears manufactured from the CVM Super Nitralloy (5Ni-2Al) material were nitrided to a Rockwell C hardness of 61.5±1, at a case depth of 0.046 to 0.061 centimeter (0.018 to 0.024 in.), with a maximum white layer of 0.0013 centimeter (0.0005 in.).

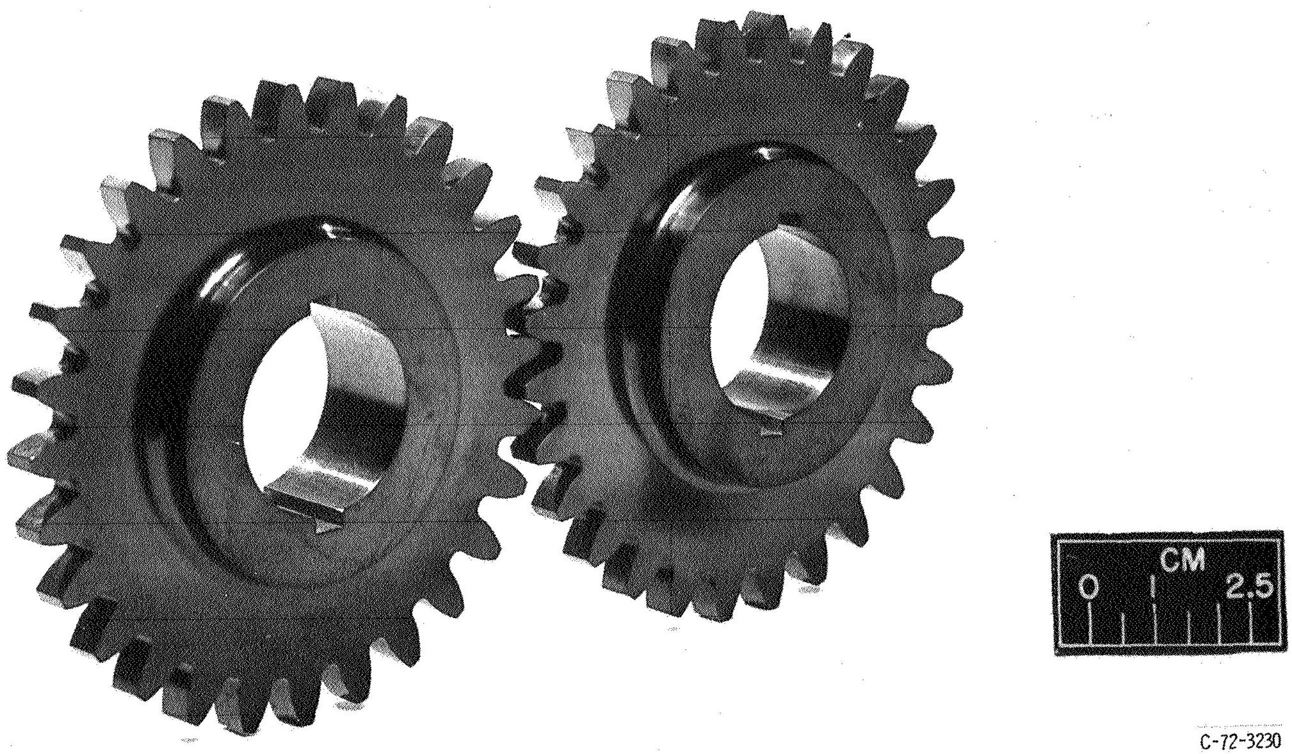


Figure 2. - CVM AISI M-50 gears with black oxide coating.

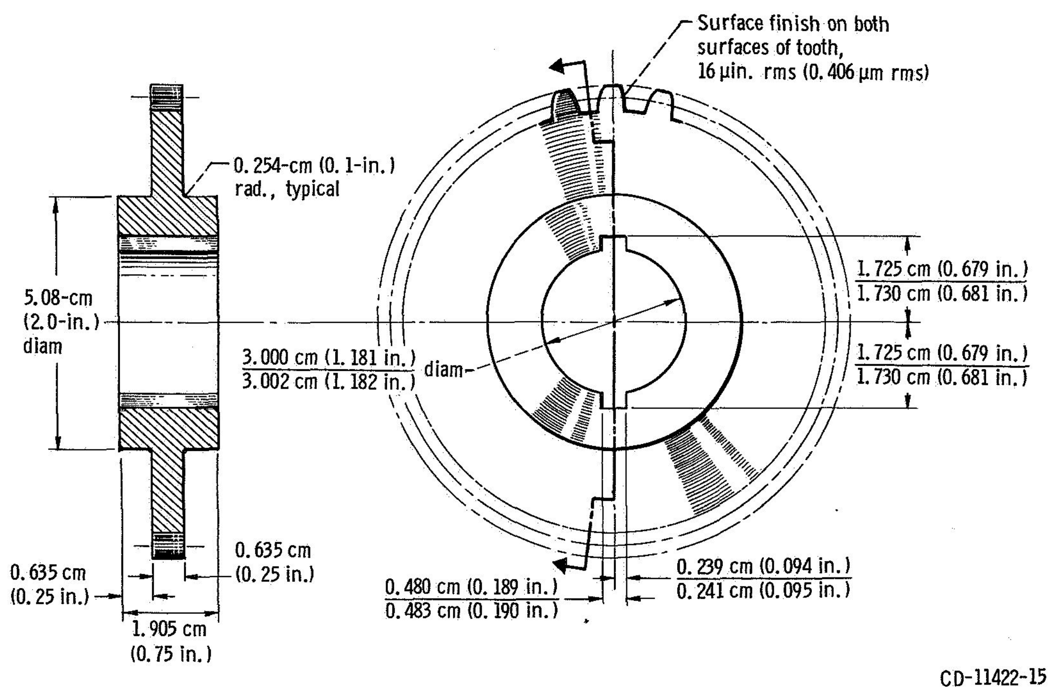


Figure 3. - Test-gear configuration. Dimensions not shown in this figure are given in table III.

TABLE III. - GEAR DATA

[Gear tolerance per AGMA class 12.]

Number of teeth	28
Diametral pitch	8
Circular pitch, cm (in.)	0.9975 (0.3927)
Whole depth, cm (in.)	0.762 (0.300)
Addendum, cm (in.)	0.318 (0.125)
Chordal tooth thickness reference, cm (in.)	0.485 (0.191)
Pressure angle, deg	20
Pitch diameter, cm (in.)	8.890 (3.500)
Outside diameter, cm (in.)	9.525 (3.750)
Root fillet, cm (in.)	0.102 to 0.152 (0.04 to 0.06)
Measurement over pins, cm (in.)	9.603 to 9.630 (3.7807 to 3.7915)
Pin diameter, cm (in.)	0.549 (0.216)
Backlash reference, cm (in.)	0.0254 (0.010)

TABLE IV. - CHEMICAL COMPOSITION OF GEAR MATERIALS BY PERCENT WEIGHT

Element	Gear material	
	AISI M-50 steel	Super Nitralloy (5Ni-2Al)
Carbon	0.85	0.24
Manganese	.28	.25
Phosphorous	.010	.005
Sulfur	.004	.003
Silicon	.23	.22
Copper	.06	-----
Chromium	4.17	.58
Molybdenum	4.23	.26
Vanadium	.97	.12
Nickel	.08	5.16
Cobalt	.03	-----
Tungsten	.08	-----
Aluminum	-----	2.06
Iron	Balance	Balance

TABLE V. - HEAT-TREATMENT PROCESS FOR AISI CVM

M-50 STEEL AND CVM SUPER NITRALLOY GEARS

(a) CVM Super Nitralloy (5Ni-2Al)

Step	Process	Temperature, K (°F)	Time, hr
1	Normalize	1200 (1700)	4
2	Rough machine	----------	---
3	Copper plate	----------	---
4	Austenitize	1172 (1650)	2.5
5	Oil quench	----------	---
6	Temper to Rockwell C 30 to 36	690 (1275)	5
7	Strip copper	----------	---
8	Semifinish machining	----------	---
9	Copper plate	----------	---
10	Stress relieve	950 (1250)	2
11	Strip copper	----------	---
12	Nitride	797 to 811	60
	Case depth, 0.046 to 0.061 cm (0.018 to 0.024 in.)	(975 to 1000)	
	Case hardness, Rockwell C 61.5		
	Core hardness, Rockwell C 44		

(b) CVM AISI M-50 steel

Step	Process	Temperature, K (°F)	Time, hr
Preliminary heat treatment after rough machining			
1	Austenitize	1117 (1550)	0.5
2	Air cool to Rockwell C 26 to 32	----------	---
3	Copper plate all over	----------	---
Final heat treatment			
4	Preheat in neutral salt bath	1075 (1475)	0.5
5	Transfer to neutral salt bath	1395 (2050)	0.5
6	Quench neutral salt bath	839 (1050)	5
7	Air cool	311 to 339 (100 to 150)	---
8	Temper	839 (1050)	2
9	Deep freeze	172 (-120)	2
10	Retemper	839 (1050)	2

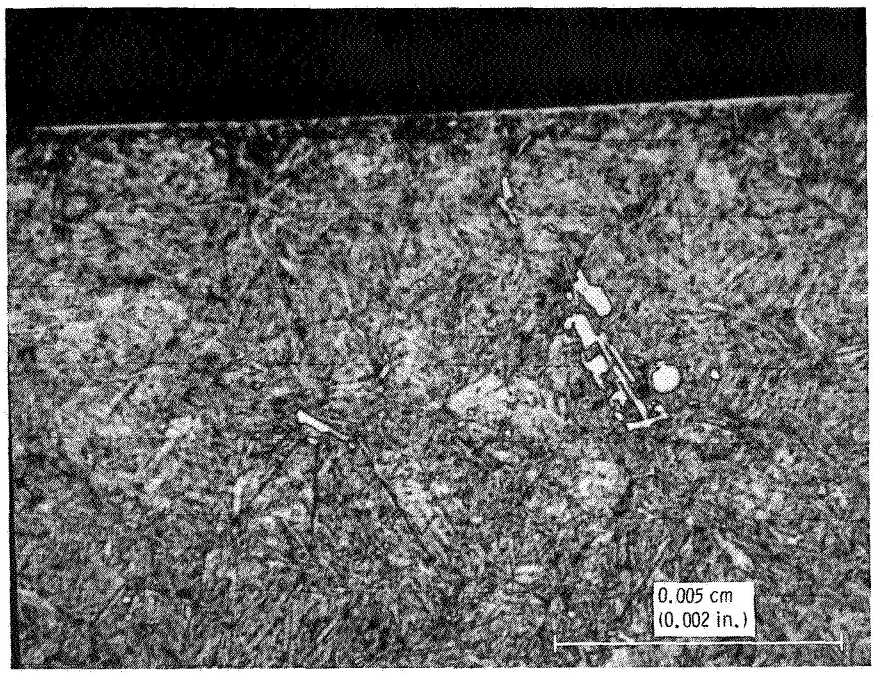


Figure 4. - Photomicrograph of etched and polished surface of AISI M-50 steel.

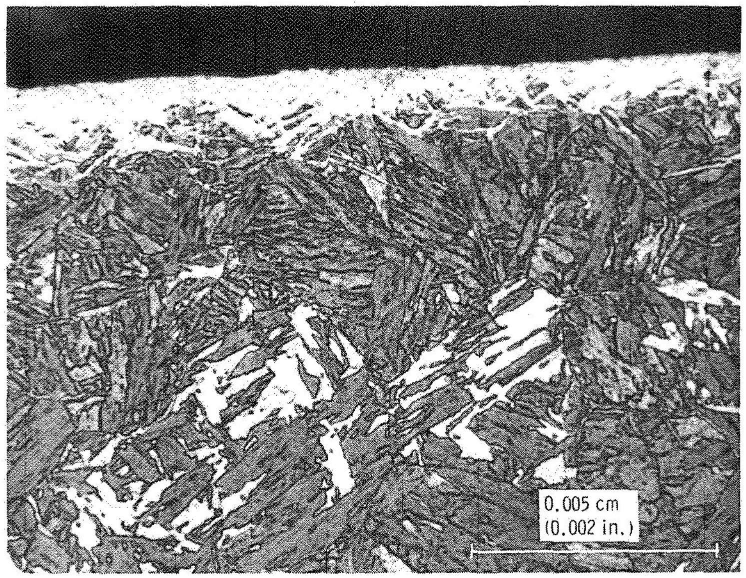
(The white layer is iron nitride which forms during the nitriding process. By proper control of the nitriding conditions, the depth of the white layer can be kept to a minimum.) The core hardness was Rockwell C 44±1. The Super Nitralloy gears were heat treated in accordance with the schedule of table V.

The gears were ground before nitriding and had a mat finish due to the nitriding process. Photomicrographs of etched and polished surfaces showing the microstructure of the Super Nitralloy material are presented in figure 5.

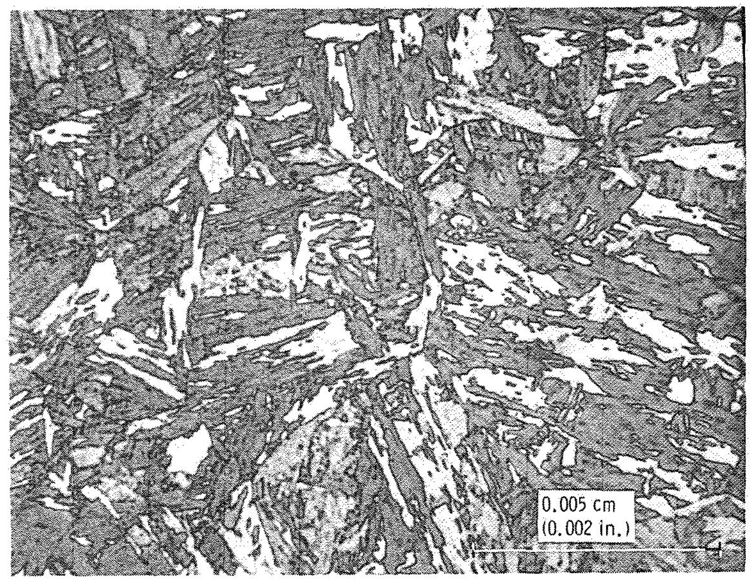
The short-term (30 min) hot hardness data (from refs. 7 and 8) for the AISI M-50 and the Super Nitralloy materials are shown in figure 6. This figure shows that the AISI M-50 material has a slightly better short-term hot hardness characteristic than the Super Nitralloy material.

Test Procedure

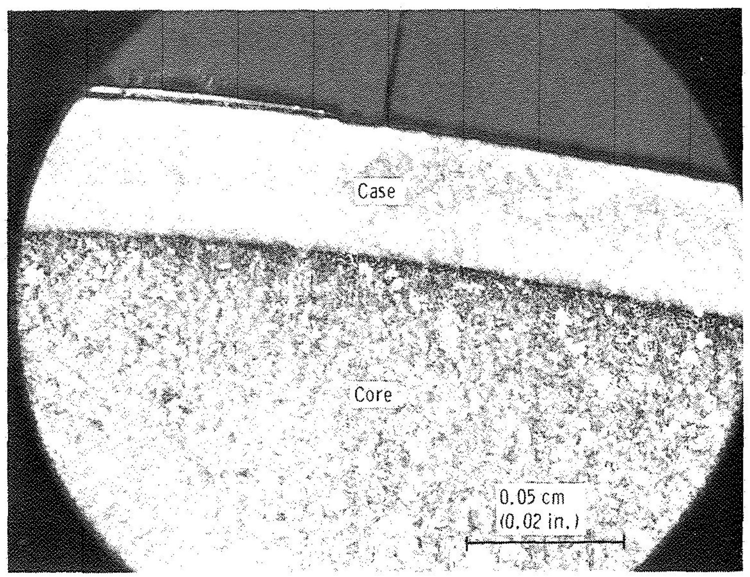
The test gears were cleaned to remove the preservative and were assembled on the test rig. The test gears were run in an offset condition, with a 0.28-centimeter (0.110-in.) tooth-surface overlap to give a load surface on the gear face of 0.25 centimeter (0.100 in.) of the 0.635-centimeter- (0.250-in.-) wide gear, thereby allowing for edge radius of the gear teeth. By testing both faces of the gears, a total of four fatigue tests



(a) Case.



(b) Core.



(c) Case and core.

Figure 5. - Photomicrographs of etched and polished surfaces of Super Nitralloy (5Ni-2Al).

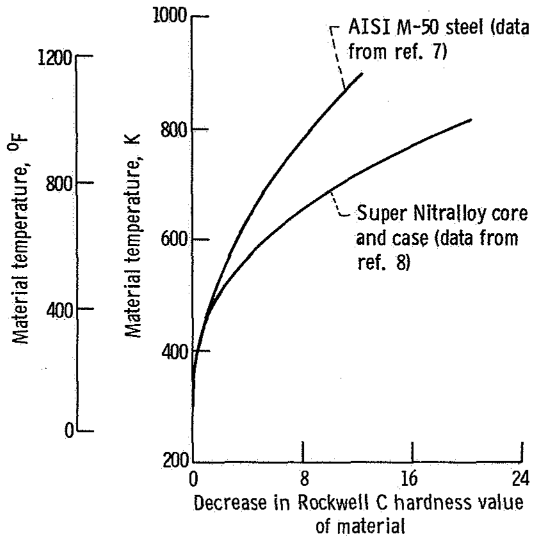


Figure 6. - Normalized short-term (30 min) hardness data (from refs. 7 and 8) for AISI M-50 and for Super Nitralloy case and core.

could be run for each set of gears. All tests were run-in at a load of 2713 newtons per centimeter of face (1550 lb/in. of face) for 1 hour. The load was then increased to 7525 newtons per centimeter (4300 lb/in.) and 190×10^7 newtons per square meter (275 000 psi) pitch-line Hertz stress.

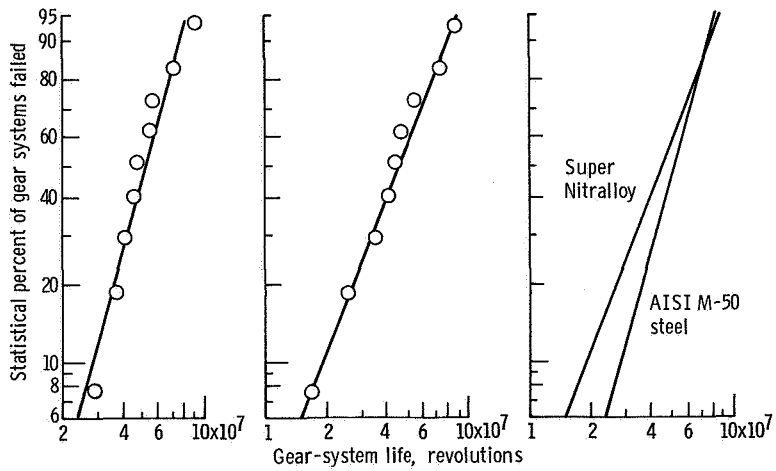
The test gears were operated at 10 000 rpm, which gave a pitch-line velocity of 46.55 meters per second (9163 ft/min). Lubricant was supplied to the inlet mesh at 800 cubic centimeters per minute at 319±6 K (115±10° F). The tests were continued 24 hours a day until they were shut down automatically by the vibration-detection transducer located on the gearbox, adjacent to the test gears. The lubricant was circulated through a 5-micrometer fiber-glass filter to remove wear particles. A total of 3800 cubic centimeters (1 gal) of lubricant was used for each test and was discarded, along with the filter element, after each test. Inlet and outlet oil temperatures were continuously recorded on a strip-chart recorder.

The pitch-line elastohydrodynamic (EHD) film thickness was calculated by the method of reference 9. 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 this gear temperature, even though the oil inlet temperature was considerably lower. It is probable that the gear surface temperature could be even higher than the oil outlet temperature, especially at the end points of sliding contact. The EHD film thickness for the above conditions was computed to be 0.65 micrometer (26 μin.), which gave a ratio of film thickness to composite surface roughness (h/σ) of 1.13.

RESULTS AND DISCUSSION

Two groups of test gears made from CVM AISI M-50 steel and CVM Super Nitralloy (5Ni-2Al) were run in pairs until a failure occurred. A total of nine tests were carried out with each gear material. Each test was terminated when a fatigue spall occurred on one of the two gears. Test results were determined by considering each pair of gears as a system of nine tests for each material and as individual gears for 18 tests each.

Pitting fatigue results for the gear system made from the AISI M-50 material are shown in figure 7(a). The failure index (i.e., the number of fatigue failures out of the



(a) AISI M-50 steel. (b) Super Nitralloy (5Ni-2Al). (c) Comparison of results.

Figure 7. - Pitting fatigue lives of spur-gear systems made of CVM AISI M-50 steel and of CVM Super Nitralloy (5Ni-2Al). Maximum Hertz stress at pitch line, 190×10^7 newtons per square meter (275 000 psi); speed, 10 000 rpm; temperature, 350 K (170° F); lubricant, super-refined naphthenic mineral oil.

number of gear sets tested) was 9 of 9. These data were analyzed by the methods of reference 10 and are summarized in table VI. The data were also reanalyzed by considering each gear as an individual specimen. These data are shown in figure 8(a) and are also summarized in table VI.

A typical fatigue spall for the AISI M-50 gears is shown in figure 9. Metallurgical examination of all failures indicated that the fatigue spalls were of subsurface origin and were initiated at the pitch circle. A cross section of a failed gear tooth is shown in the photomicrograph of figure 10. The subsurface-initiated spall is characterized by a plurality of subsurface cracks emanating below the surface and propagating into a crack network. Eventually these develop into a typical fatigue spall or pit. An unfailed gear tooth run to 91 and 73 hours, respectively, on the two tracks is shown in figure 11.

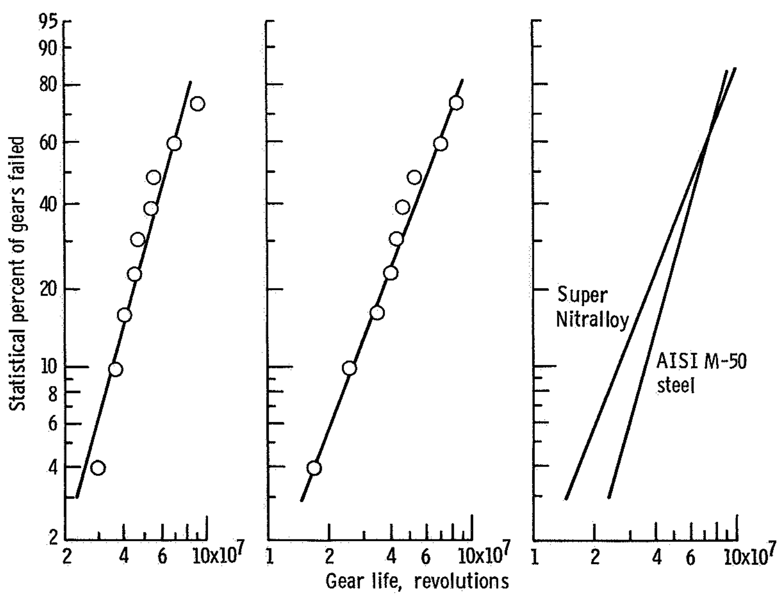
TABLE VI. - FATIGUE LIFE RESULTS FOR CVM AISI M-50 STEEL AND CVM SUPER NITRALLOY (5Ni-2Al) SPUR GEARS

[Maximum Hertz stress at pitch line, 190×10^7 N/m^2 (275 000 psi); speed 10 000 rpm; temperature, 350 K (170° F); lubricant, super-refined naphthenic mineral oil.]

Material	Failure index (a)	Pitting fatigue life				Weibull slope	Confidence number (10-percent life relative to Super Nitralloy), percent (b)
		hr		Number of revolutions			
		B_{10}	B_{50}	B_{10}	B_{50}		
Gear system							
M-50	9 of 9	46.4	85.8	27.8×10^6	50.8×10^6	3.1	70
Super Nitralloy	9 of 9	31.6	73.8	18.9×10^6	44.2×10^6	2.2	--
Individual gear							
M-50	9 of 18	57.8	105.8	34.6×10^6	63.4×10^6	3.1	65
Super Nitralloy	9 of 18	43.0	100.7	25.8×10^6	60.3×10^6	2.2	--

[a]Number of failures out of number of specimens tested.

[b]Number of times out of 100 that additional tests will be ranked as shown.



(a) AISI M-50 steel. (b) Super Nitralloy (5Ni-2Al). (c) Comparison of results.

Figure 8. - Pitting fatigue lives of spur gears made of CVM AISI M-50 steel and of CVM Super Nitralloy (5Ni-2Al). Maximum Hertz stress at pitch line, 190×10^7 newtons per square meter (275 000 psi); speed, 10 000 rpm; temperature, 350 K (170° F); lubricant, super-refined naphthenic mineral oil.

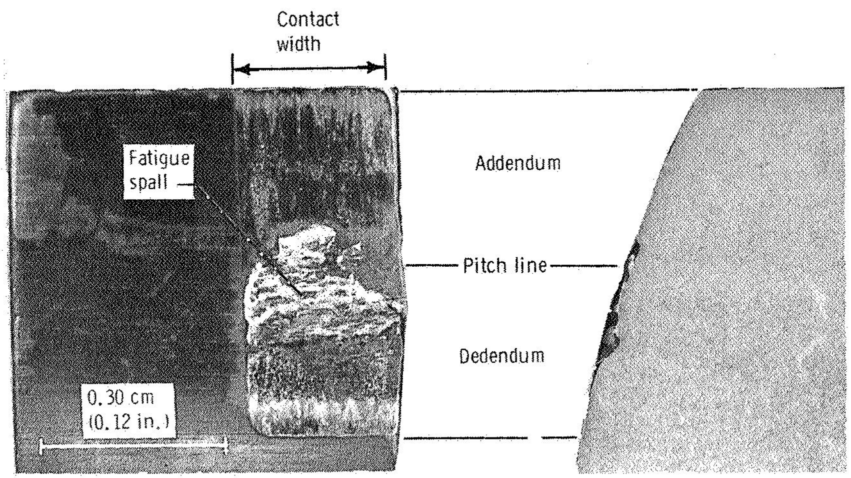


Figure 9. - Typical pitch-line fatigue spall of AISI M-50 steel gear. Maximum Hertz stress at pitch line, 190×10^7 newtons per square meter (275 000 psi); speed, 10 000 rpm; temperature, 350 K (170^0 F); lubricant, super-refined naphthenic mineral oil.

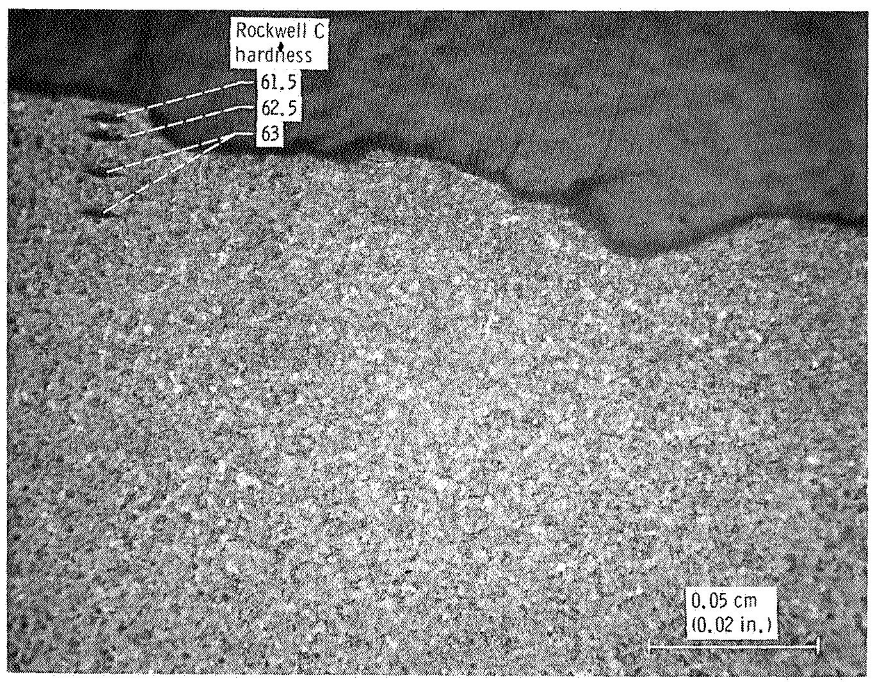


Figure 10. - Photomicrograph of pitch-line fatigue spall on AISI M-50 steel gear tooth. Maximum Hertz stress at pitch line, 190×10^7 newtons per square meter (275 000 psi); speed, 10 000 rpm; temperature, 350 K (170^0 F); lubricant, super-refined naphthenic mineral oil.

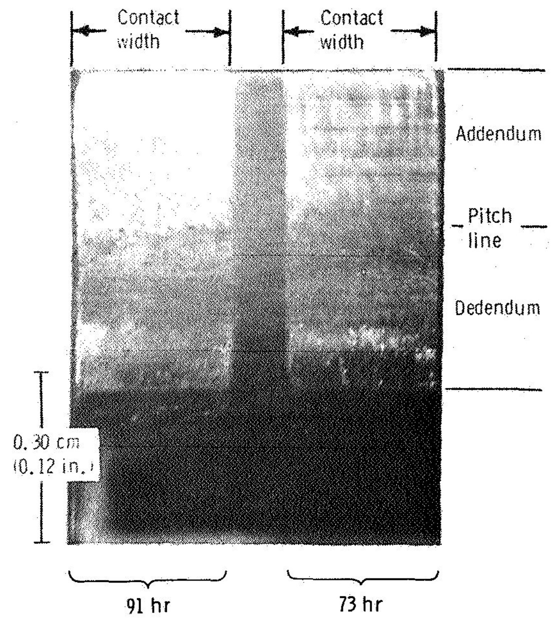


Figure 11. - Typical unfailed gear tooth, with contact surfaces that had completed 91 hours and 73 hours. Maximum Hertz stress at pitch line, 190×10^7 newtons per square meter (275 000 psi); speed, 10 000 rpm; temperature, 350 K (170° F); lubricant, super-refined naphthenic mineral oil.

In order to study the wear of the gears, surface traces in the axial direction across the face of the AISI M-50 gear teeth were made at the addendum, the pitch line, and the dedendum. Typical results from these data are summarized in table VII. There was approximately 13 micrometers (500 μin.) average wear across the tooth face. It is thought that this amount of wear is due to "run in" and is not progressive in nature. The wear at the pitch line, where rolling occurs, was somewhat less, as would be expected. However, no systematic measurements of wear with time were made which would verify this speculation.

The fatigue lives of the gear sets made from Super Nitralloy are shown in figure 7(b). Pitting fatigue lives of individual gears are shown in figure 8(b). These data are summarized in table VI. As with the AISI M-50 material, the fatigue spalls were of subsurface origin. A typical fatigue spall with the Super Nitralloy gears is shown in figure 12. A photomicrograph of a cross section of a spall is shown in figure 13. The unfailed Super Nitralloy gear teeth are identical in appearance to the AISI M-50 gear teeth. These data indicate that the M-50 gears have a life 50 percent greater than the Super Nitralloy gears at a 90-percent probability of survival.

TABLE VII. - WEAR OF AISI CVM M-50 STEEL AND CVM SUPER NITRALLOY (5Ni-2Al) GEAR MATERIAL

[Maximum Hertz stress at pitch line, 190×10^7 N/m^2 (275 000 psi); speed, 10 000 rpm; temperature, 350 K (170° F); lubricant, super-refined naphthenic mineral oil.]

Gear material	Running time, hr (a)	Wear depth, μm (μin.)		
		Addendum	Pitch	Dedendum
CVM AISI M-50 steel	48	10.8 (433)	12.2 (487)	13.7 (547)
	66	12.0 (480)	6.3 (253)	23.7 (947)
	76	14.2 (567)	6.0 (240)	8.3 (333)
CVM Super Nitralloy (5Ni-2Al)	42	12.3 (493)	5.7 (227)	9.5 (380)
	76	1.8 (73)	2.0 (80)	3.5 (140)
	118	6.0 (240)	4.2 (167)	16.7 (667)
	140	5.3 (213)	4.0 (160)	7.5 (300)

[a]Measurements were on different specimen for different time period.

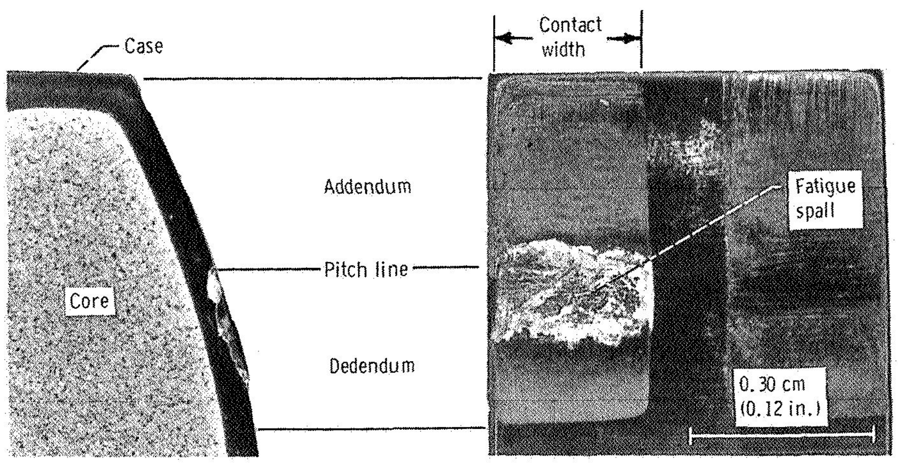


Figure 12. - Typical pitch-line fatigue spall of Super Nitralloy (5Ni-2Al) gear. Maximum Hertz stress at pitch line, 190×10^7 newtons per square meter (275 000 psi); speed, 10 000 rpm; temperature, 350 K (170° F); lubricant, super-refined naphthenic mineral oil.

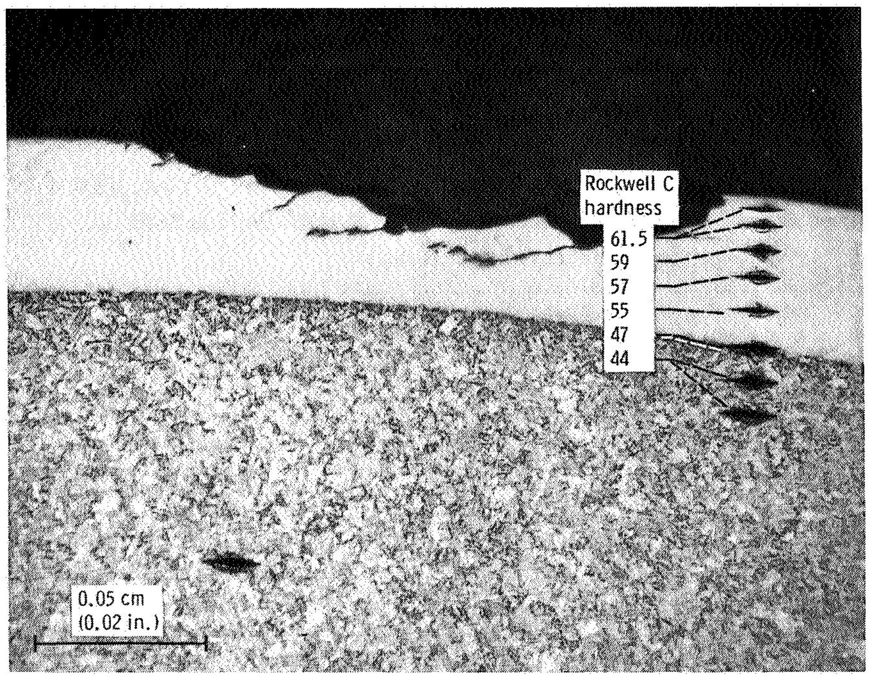


Figure 13. - Photomicrograph of pitch-line fatigue spall on Super Nitralloy (5Ni-2Al) gear tooth. Maximum Hertz stress at pitch line, 190×10^7 newtons per square meter (275 000 psi); speed, 10 000 rpm; temperature, 350 K (170° F); lubricant, super-refined naphthenic mineral oil.

Wear measurements, summarized in table VII, indicated less wear for the Super Nitralloy gear teeth than for the M-50 gears. In general, the average wear depth across the tooth face of the Super Nitralloy gear teeth was approximately 8 micrometers (300 μin.). This amount was less than with the M-50 material. As with the M-50 gears, there was no general relation between running time and wear. The measured wear was apparently due to "run in," as with the M-50 material.

The confidence that can be placed in the experimental results was determined statistically with the use of the methods given in reference 10. The Super Nitralloy gears were compared with the M-50 gears. Confidence numbers for the 90-percent probability of survival, or 10 percent life, were calculated and are presented in table VI. The confidence of 70 percent for M-50 relative to Super Nitralloy means that 70 out of 100 times the 10-percent life of the Super Nitralloy gears will be less than that of the M-50 gears. A 68-percent confidence is approximately equal to a one-sigma deviation, which, for statistical purposes, is considered to be insufficient to conclude that there is any difference in the 10-percent life between materials. Hence, from these data, the fatigue-life difference between the M-50 and the Super Nitralloy steels can be considered to be statistically insignificant at nominal temperatures.

Several spalled gears of both materials were deliberately run for several hours in this condition. For the M-50 gears, the spalled tooth would fracture, generally within a

2-hour period or within 1.2×10^6 stress cycles. This was not totally unexpected, inasmuch as the M-50 material is very notch sensitive. The crack size necessary for catastrophic crack growth is very small. Thus, when a fatigue spall (notch) forms, the tooth becomes susceptible to fatigue fracture.

The Super Nitralloy, while having a hard surface, has a soft, ductile core. Since the rate of crack growth is much lower in the ductile core, the material is notch insensitive. Thus, when a fatigue spall (notch) forms, the tooth is not very susceptible to fatigue fracture. This was verified in the tests reported herein, where none of the spalled teeth that were deliberately overrun failed because of fracture.

These results verify the need for a soft core in critical applications where the probability of failure is high. However, the M-50 material, with a Rockwell C hardness of 62, had a longer life (although statistically insignificant) than the Super Nitralloy material, which has a case Rockwell C hardness of 61.5. Based on the hardness characteristics of the two materials, the M-50 material may have greater high-temperature pitting fatigue life potential because of its higher hot hardness. The Super Nitralloy material is probably usable to 588 K (600° F) if oxidation stability is discounted. This would imply that the fabrication of gears from an M-50 type material with a soft core would be beneficial to long gear life.

SUMMARY OF RESULTS

Two groups of 8.89-centimeter- (3.5-in.-) pitch-diameter spur gears with standard 20° involute tooth profile without tip relief, made from consumable-electrode vacuum-melted (CVM) AISI M-50 steel and CVM Super Nitralloy (5Ni-2Al) were tested under conditions that produced fatigue pitting. Test conditions included a speed of 10 000 rpm and a maximum Hertz stress of 190×10^7 newtons per square meter (275 000 psi) at the gear pitch line. The lubricant was a super-refined naphthenic mineral oil with an additive package. The following results were obtained:

1. The AISI M-50 gears had lives approximately 50 percent longer than the Super Nitralloy gears at a 90-percent probability of survival. However, the difference in life was not considered statistically significant.

2. Both the AISI M-50 and the Super Nitralloy gears failed from classical pitting fatigue at the pitch circle. That is, the gear teeth failed because of spalling which originated from subsurface initiated cracks. The spall was limited in area and depth of penetration.

3. The AISI M-50 gear sets having a spalled gear tooth which were deliberately overrun, failed within 2 hours after spalling had occurred because of tooth fracture fatigue. Under the same conditions, the Super Nitralloy material did not fail.

4. Wear measurements across the gear teeth indicated that more wear occurred with

the AISI M-50 material than did with the Super Nitralloy. However, the difference in wear was not considered significant.

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U. S. Army Air Mobility R & D Laboratory,
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REFERENCES

1. Seabrook, John B.; and Dudley, Darle W.: Results of a Fifteen-Year Program of Flexural Fatigue Testing of Gear Teeth. J. Eng. Ind., vol. 86, no. 3, Aug. 1964, pp. 221-239.
2. Zaretsky, E. V.; and Anderson, W. J.: Effect of Materials: General Background. Interdisciplinary Approach to the Lubrication of Concentrated Contacts. P. M. Ku, ed., NASA SP-237, 1970, pp. 379-408.
3. Lemanski, A. J.; and Rose, H. J.: Evaluation of Advanced Gear Materials for Gear Boxes and Transmissions. Rep. D210-10345-1, Boeing Co., Sept. 1971.
4. Beane, G. A., IV; and Lawler, C. W.: Load-Carrying Capacities of Gear Lubricants of Different Chemical Classes Based on Results Obtained with WADD High-Temperature Gear Machine Used with Induction-Heated Test Gears. Southwest Research Inst. (AFAPL-TR-65-23, AD-620294), Apr. 1965.
5. Jackson, Earl G.; Muench, Charles F.; and Scott, Ernest H.: Evaluation of Gear Materials Scoring at 700 F. ASLE Trans., vol. 3, no. 1, 1960, pp. 69-82.
6. Bamberger, Eric N.; Zaretsky, Erwin V.; and Anderson, William J.: Fatigue Life of 120-mm Bore Ball Bearings at 600° F with Fluorocarbon, Polyphenyl Ether, and Synthetic Paraffinic Base Lubricants. NASA TN D-4850, 1968.
7. Chevalier, James L.; Dietrich, Marshall W.; and Zaretsky, Erwin V.: Short-Term Hot Hardness Characteristics of Rolling-Element Steels. NASA TN D-6632, 1972.
8. Chevalier, James L.; Dietrich, Marshall W.; and Zaretsky, Erwin V.: Hot Hardness Characteristics of Ausformed AISI M-50, Matrix II, WD-65, Modified AISI 440-C, and Super Nitralloy. NASA TN D-7244, 1973.

9. Dowson, Duncan; and Higginson, G. R.: Elasto-Hydrodynamic Lubrication. Pergamon Press, 1966.

10. Johnson, Leonard G.: The Statistical Treatment of Fatigue Experiments. Elsevier Publ. Co., 1964.

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16. Abstract
Two groups of 8.89-centimeter- (3.50-in.-) pitch-diameter spur gears, without tip relief, made from consumable-electrode vacuum-melted (CVM) AISI M-50 steel and CVM Super Nitralloy (5Ni-2Al) were tested under conditions which produced fatigue pitting. The M-50 gears had fatigue lives approximately 50 percent longer than the Super Nitralloy gears. Both groups of gears failed by classical rolling-element fatigue at the pitch circle. When the gears were overrun past initial spall formation, the spalled M-50 gear teeth failed by fatigue fracture. The M-50 material had higher wear than the Super Nitralloy material. Differences in fatigue life and wear were not considered statistically significant.

17. Key Words (Suggested by Author(s))
Spur gear; Pitting fatigue; AISI M-50 steel gear; Super Nitralloy gear; Surface endurance

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