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Prove di fatica a flessione di ingranaggi cementati per elicotteri (Bending Fatigue Tests of Helicopter Case Carburized Gears: Influence of Material, Design and Manufacturing Parameters)

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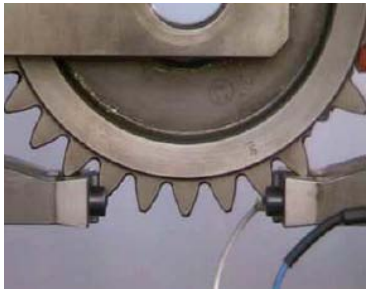
Abstract

- STF (Single Tooth Fatigue) Tests on Aerospace Gears
- Test Scheme and Test Rig Design
- 4 Test Groups: material, tooth root, grinding method
- Comparative tests up to 10 million cycles
- Extended tests up to 100 million cycles for one test group
- Ultimate Load Test
- S-N Shape Curves
- Conclusions and Future Developments



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Introduction

- **Increasing requirements of safety, reliability, performances: increasing tooth bending loads**
- **Influence of several aspects: design, manufacturing, material, cleanliness, case depth, residual stresses, etc.**
- **Loads at very high cycles ranges and short duration overloads: appropriate S-N curves**
- **Precise knowledge of allowable stresses to introduce in rating formulas**
- **Limitations of Rating Standards**

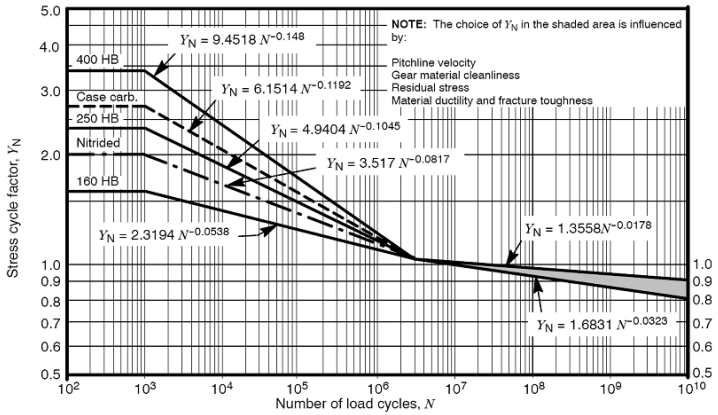
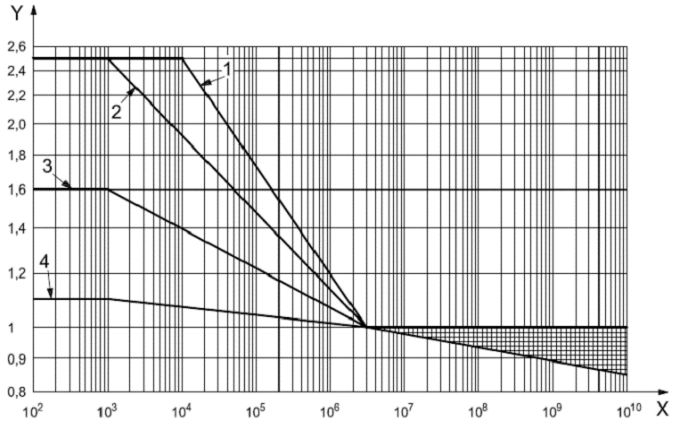
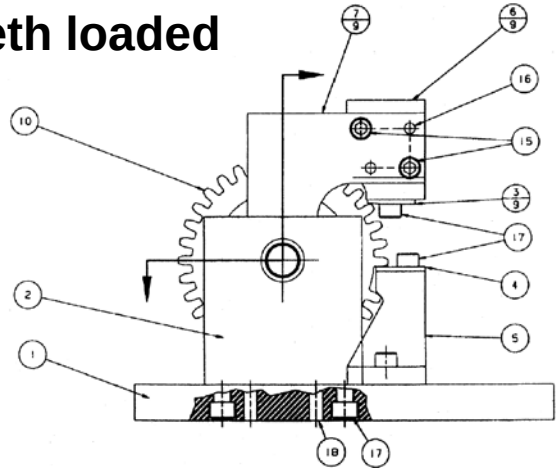


Figure 18 – Bending strength stress cycle factor, Y_N

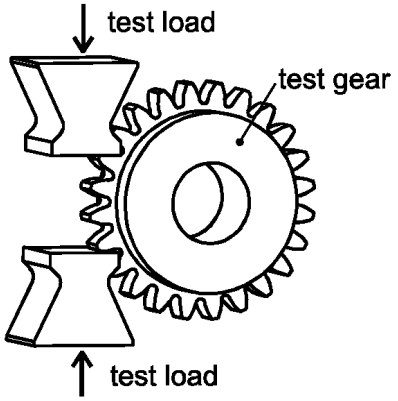


Bending Fatigue Tests

- **STF vs. Rolling Tests :**
  - **Different R (0.1 vs 0.0)**
  - **Statistical aspects: different number of teeth loaded**



- **STF tests:**
  - **Gear Blank supported, e.g. according to SAE J1619 (more typical in US)**
  - **Gear Blank not supported, thanks to the properties of Wildhaber Span (more typical in EU)**



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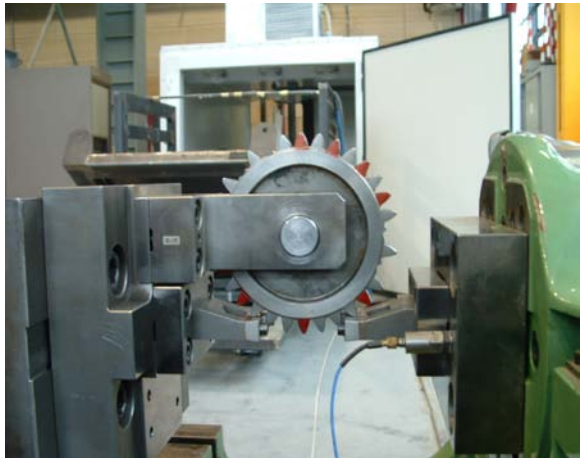
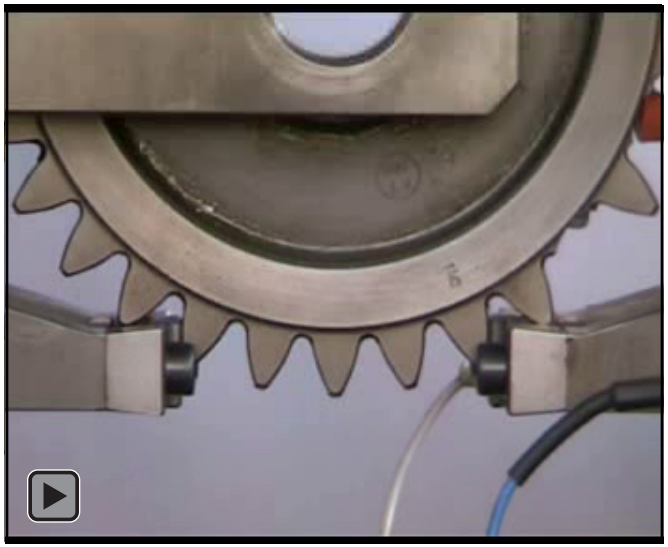
AW – POLIMI STF Test Rig

- **Specifically designed for the present research program**
- **Suited for both testing schemes, by changing the length of the left anvil**
- **Present tests performed with blank not supported**
- **Mechanical Resonance 60 kN testing machine**





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Gear data and test groups

Main Gear Data

Number of Teeth	[-]	32
Normal Module	[mm]	3.773
Helix Angle	[°]	0.0
Normal Pressure Angle	[°]	22.5
Transversal Pressure Angle	[°]	22.5
Transversal Module	[mm]	3.773
Working Pitch Diameter	[mm]	120.74
Base Diameter	[mm]	111.55
Effective Face Width	[mm]	15.0
Tip Diameter	[mm]	130.0

Test Groups

Test Group Number	Material	Manufacturing
451	VIM-VAR 9310	Ground fillet, shotpeened
551	VIM-VAR 9310	Unground fillet, shotpeened
651	VAR 9310	Ground fillet, shotpeened
751	VIM-VAR EX 53	Ground fillet, shotpeened

Phase 1: tests with runout at 10 million cycles on all the test groups

Phase 2: tests with runout at 100 million cycles on test group 451

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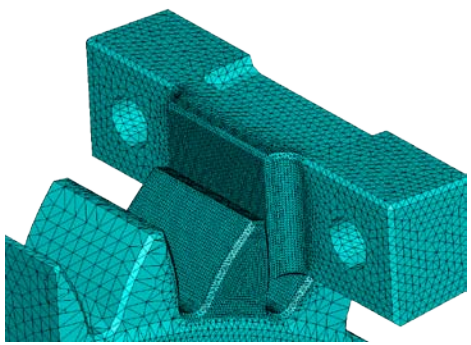
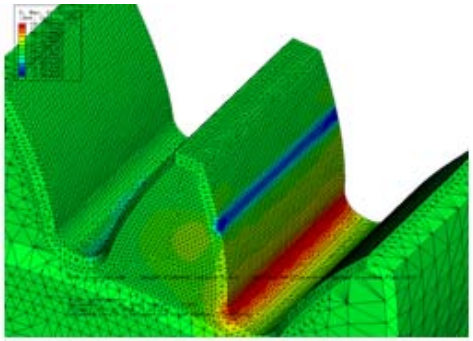
Test loads and tooth root stresses

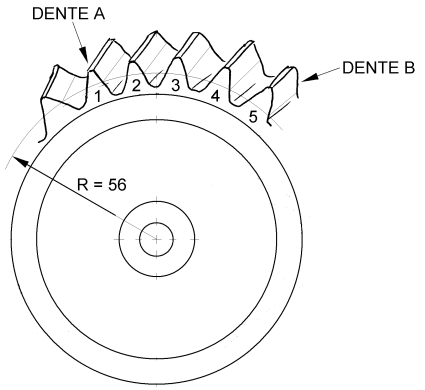
ANSI/AGMA 2101-D04 $\sigma_F = \frac{F_t}{b \cdot m_t} \cdot \frac{1}{Y_J}$

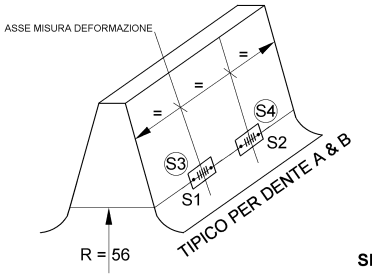
Strain Gauges

FEM









SKETCH VARIE-18
LPS. 25-10-2006

Test group	Fillet geometry	Load [kN]	FEM stress [MPa]	Strain gauge stress [MPa]	AGMA 2101-D04 bending stress [MPa]
451, 651, 751	Ground	10	421.9	442.8	382.2
551	Unground	10	417.6	427.3	361.6

S-N curves

AW rating practice is based on the use of continuos curves of the family:

S = stress
S_L= fatigue limit
N = number of cycles
A, B, C, H = constants

$$\frac{S}{S_L} = H + A \cdot (N + C)^B$$

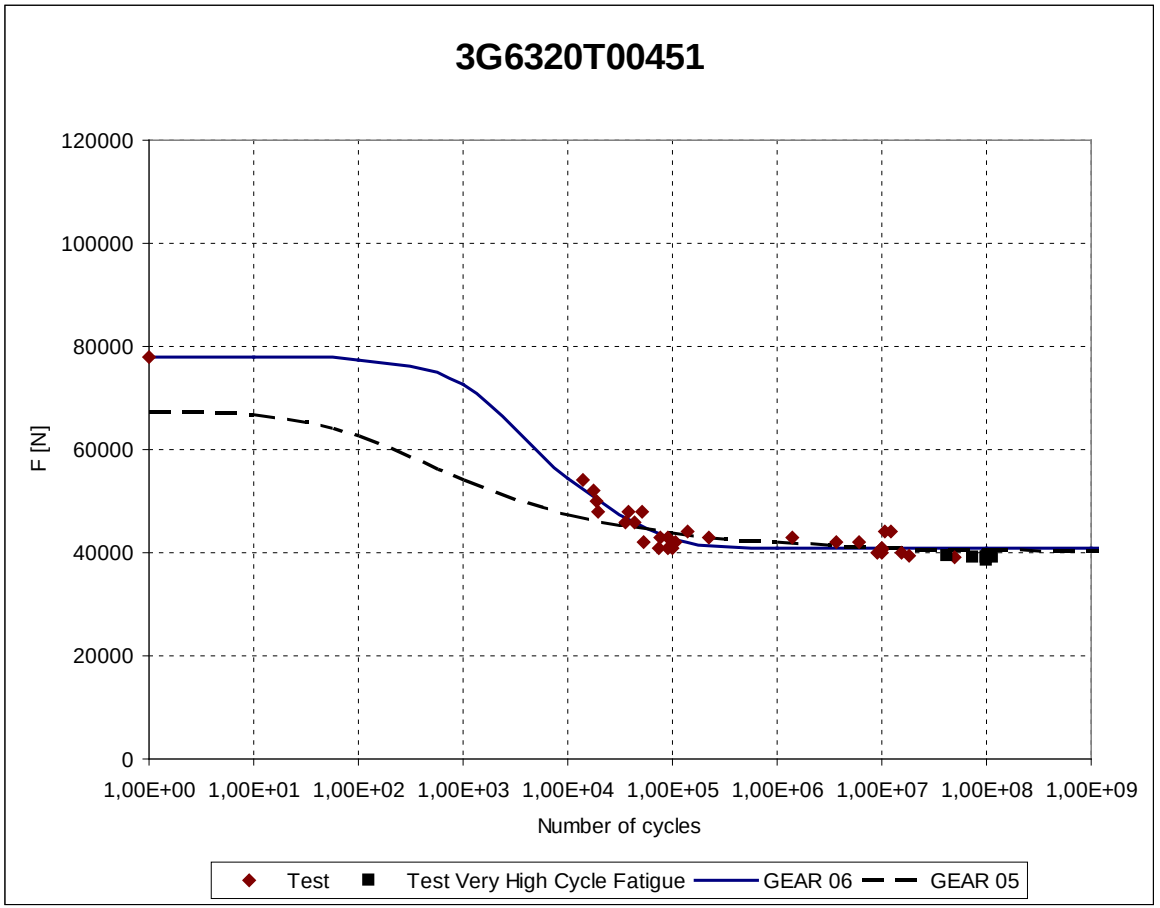
- **Various curves,named GEAR XX and corresponding to different values of the constants, both from AW experience and from other sources have been cosidered**

- **Two of them have proved to best fit test data:**

GEAR 05: constants from previous AW practice
GEAR 06: constants calculated by best fitting the the present data

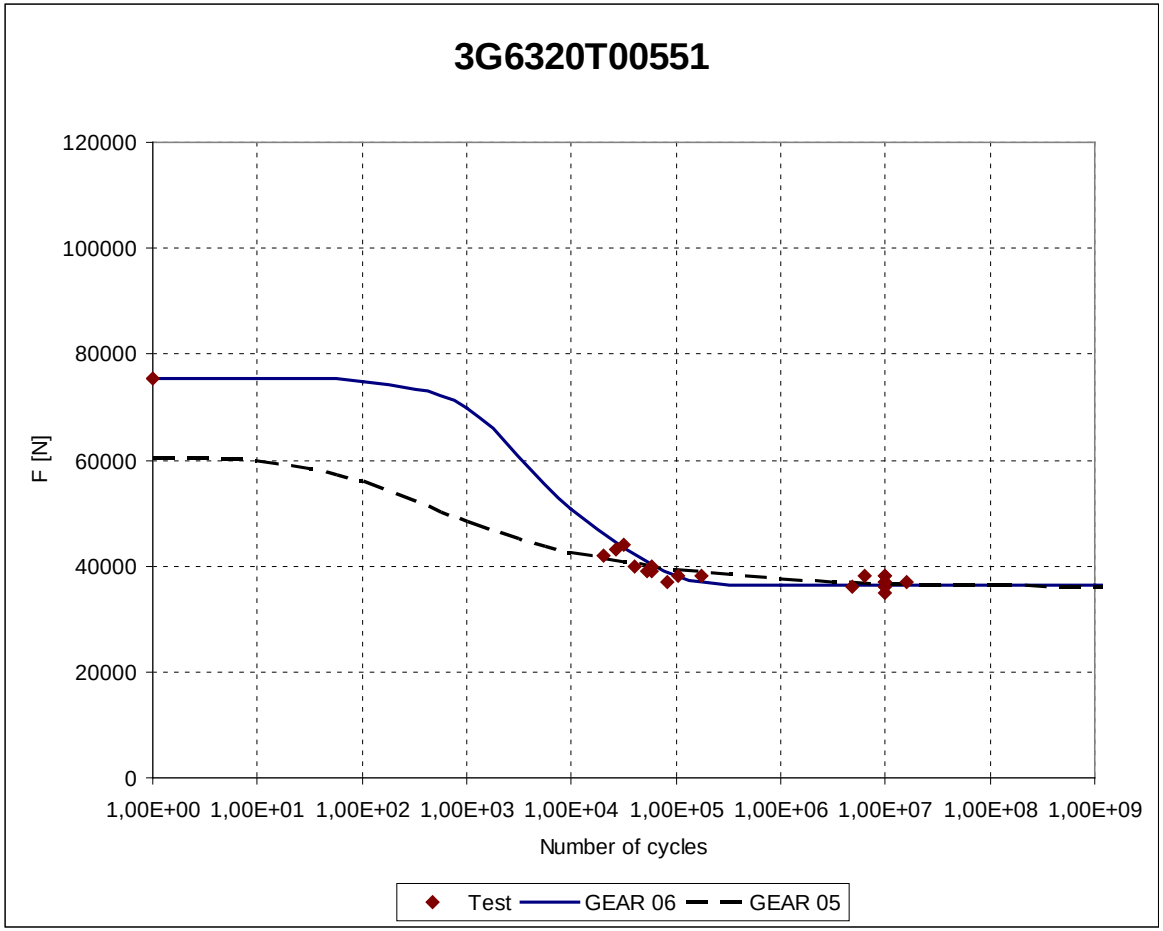
Results 451

F – N diagram with test points, GEAR 05 and GEAR 06 (phase two data included)



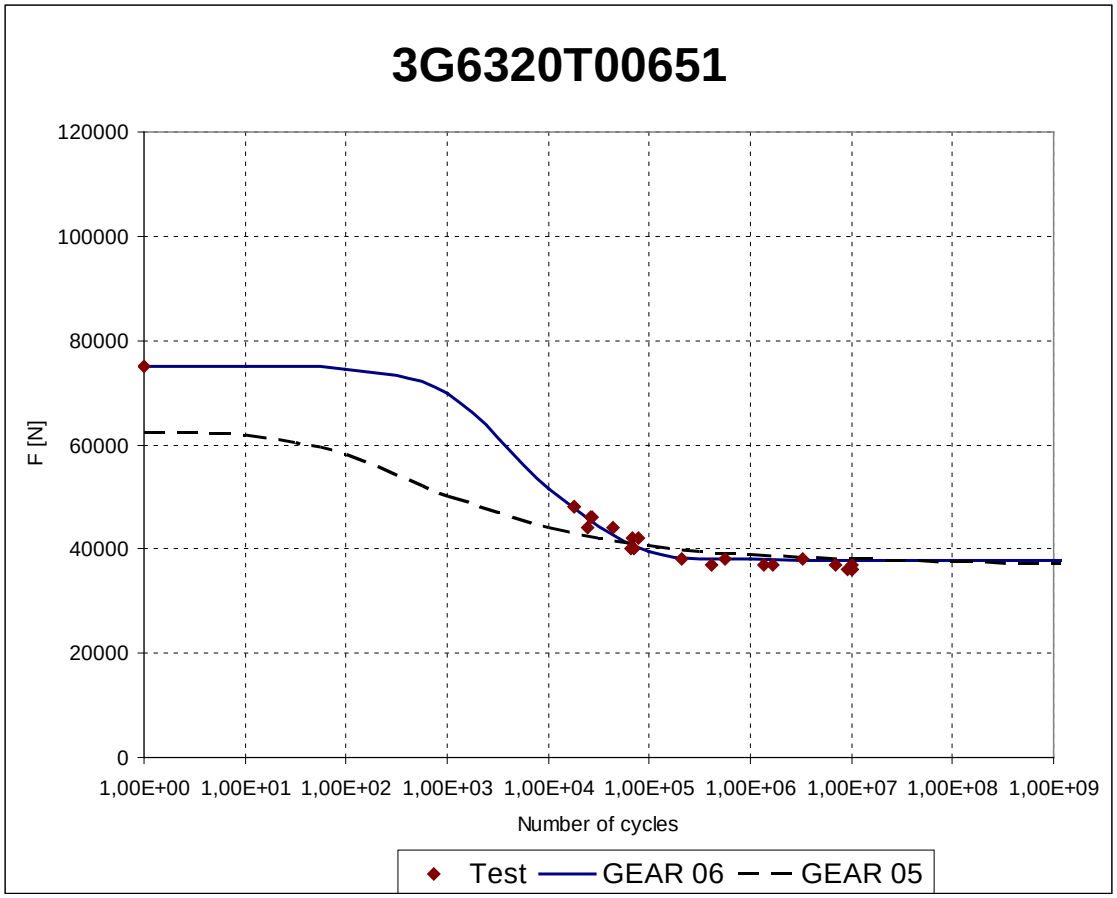
Results 551

F – N diagram with test points, GEAR 05 and GEAR 06



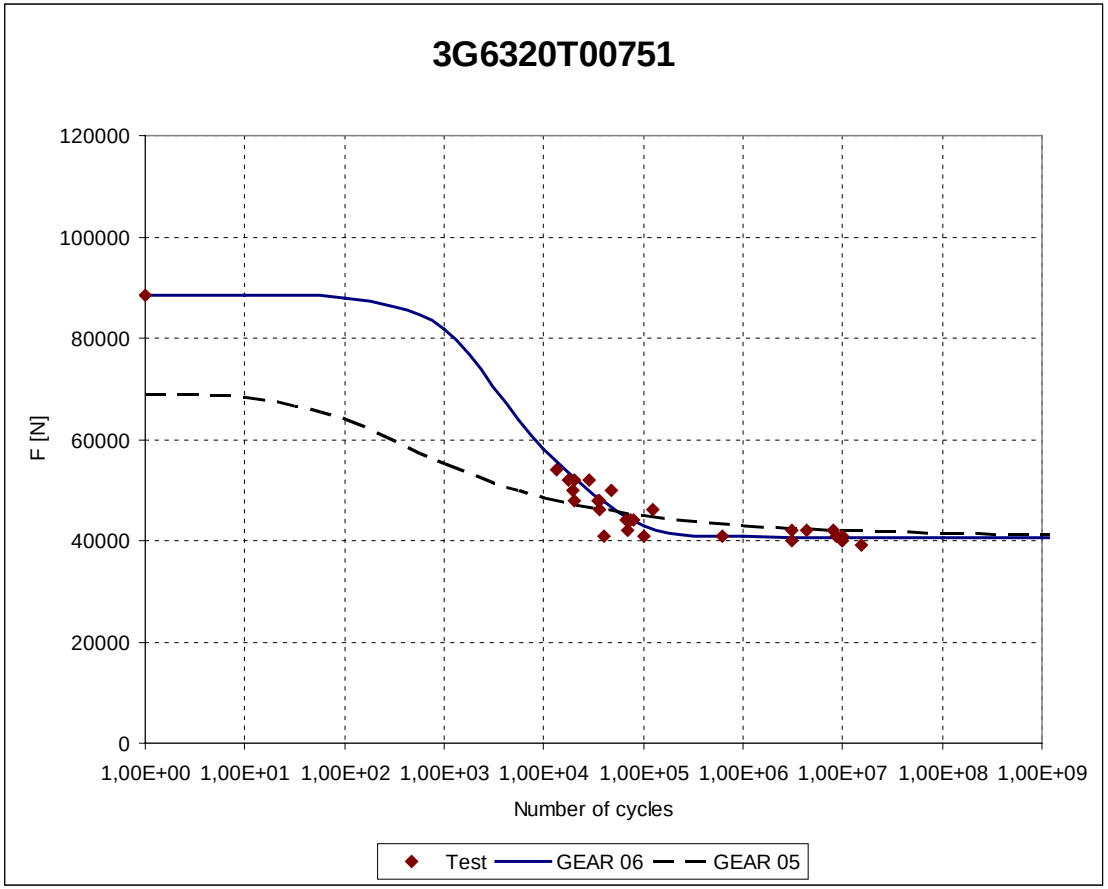
Results 651

F – N diagram with test points, GEAR 05 and GEAR 06



Results 751

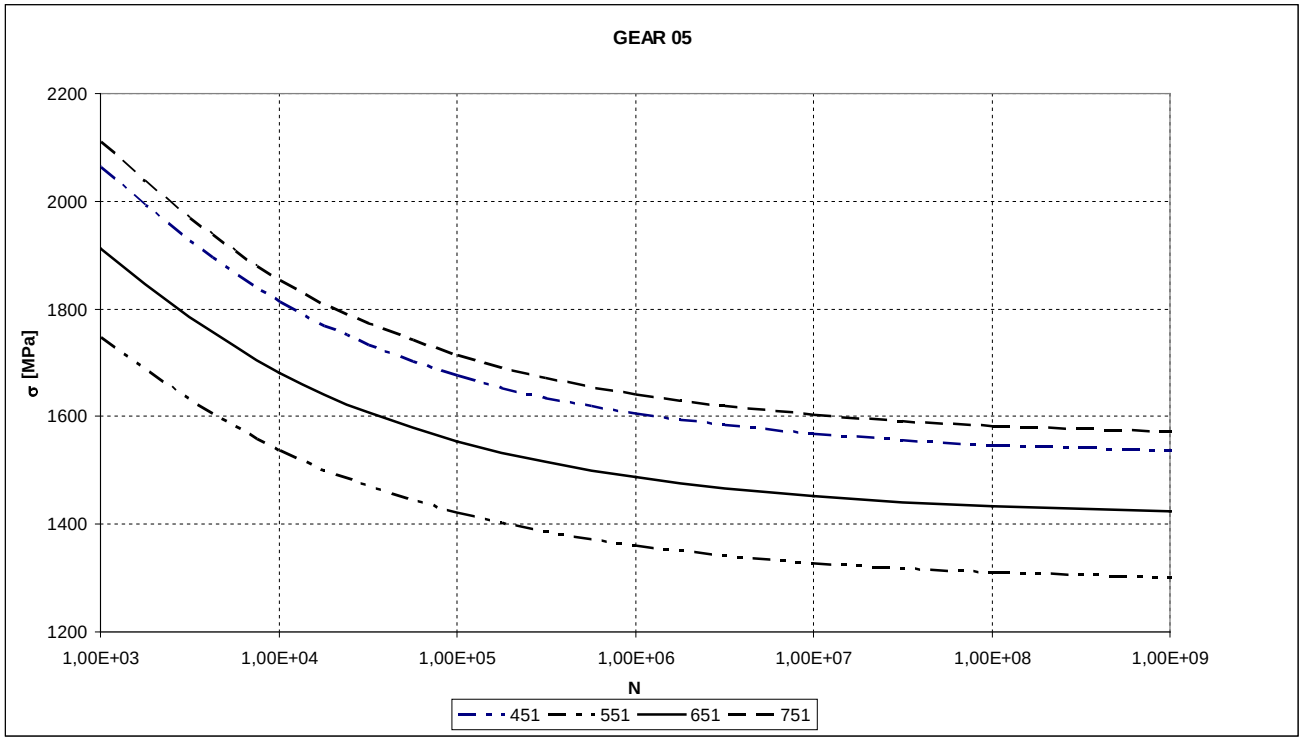
F – N diagram with test points, GEAR 05 and GEAR 06



Comparison

S-N curve

GEAR 05



Test group	451 1st phase	451 1st + 2nd	551	651	751
Fatigue Limit [N]	40,281	39,928	35,758	36,989	40,819
Fatigue Limit [MPa]	1,540	1,526	1,293	1,414	1,560

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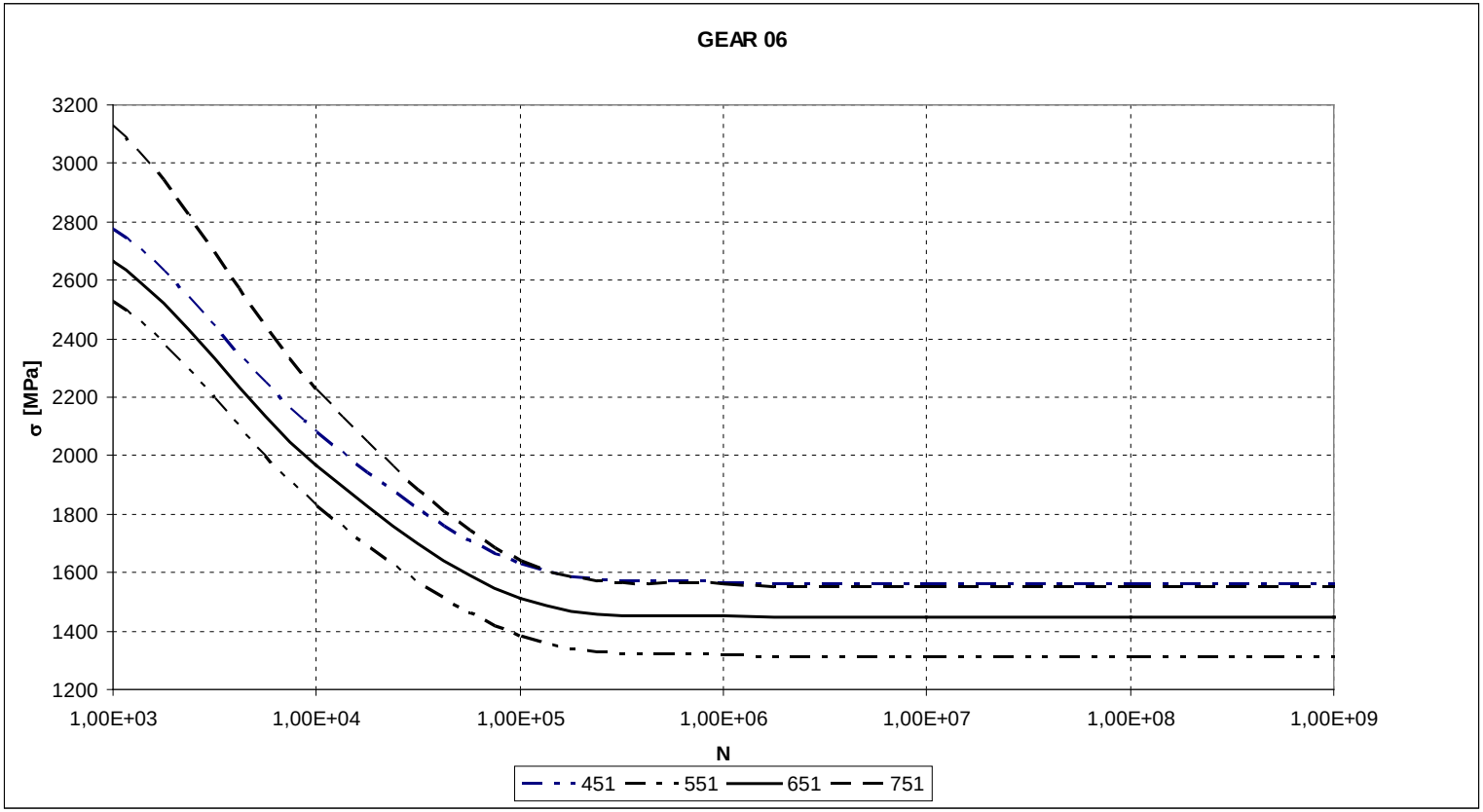
Comparison

S-N curve

GEAR 06



Additional activities: ultimate load tests

Ultimate load/Fatigue limit ratio

Obtained range: 1.93 to 2.17

Consistent with the maximum values of Y_N given by standards for case carburized gears

ISO = 2.5

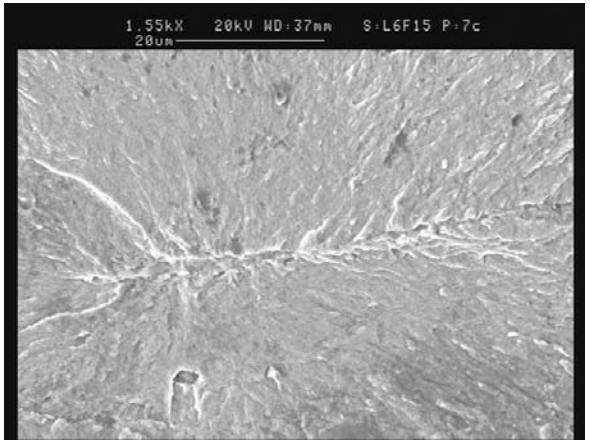
AGMA = 2.7

Additional activities: crack nucleation and propagation

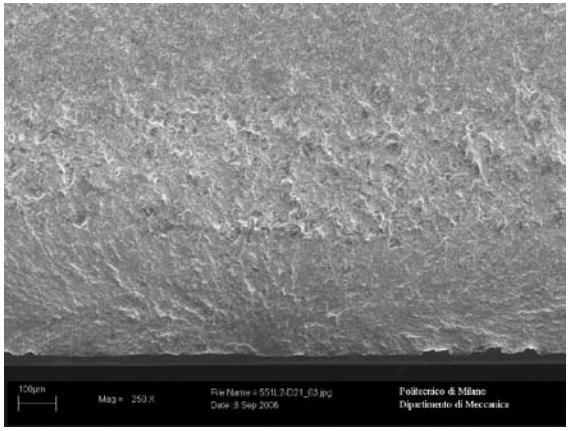
Failure surface shape:

typical of case carburized 9310

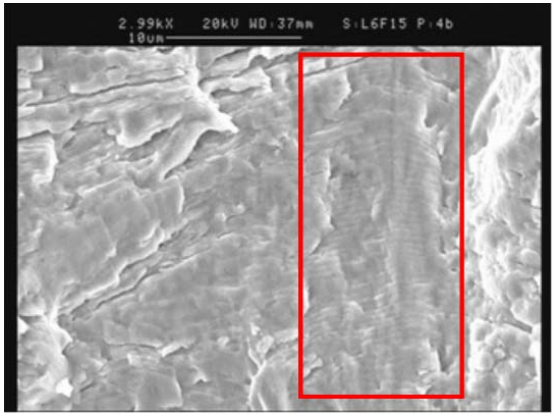
Nucleation corresponding to a non homogeneity of the material



Nucleation without a defect or inclusion



Crack growth marks



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Conclusions

- The extensive campaign has given precise information on fatigue limits of the four tests groups, both in absolute and relative terms.

- Analysis of the results with different shape curves
-
- Phase 1: tests up to 10 million cycles, ***102*** gear tooth specimens, ***434*** million cycles,
- Phase 2: tests up to 100 million cycles, 8 specimens, ***734*** million cycles

- Very high cycle tests confirm the estimations done on the basis of the shorter ones.

- The test procedure developed has now become the standardized approach at AgustaWestland to evaluate, compare and qualify new materials, new processes, new designs

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Current and future developments

- **The test program is continuing with tests on nitriding gears.**
- **Tests in the low cycle range on carburised case hardened gears with an hydraulic testing machine both under constant and variable amplitude loading.**
- **In order to improve the transferring of test data to transmission design, planned some bending fatigue rolling tests on a back-to-back rig.**

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