PROJECT FINAL REPORT

("**Publishable**"
or
"**Use and dissemination of foreground**"
or
"**Societal implications**")

Grant Agreement number: CS-GA-2009-255034

Project acronym: ABAG

Project title: Power Gear Box (PGB) advanced planet bearings development

Funding Scheme: Industry – 50%

Period covered: from 01.01.2010 to 31.12.2013

Name of the scientific representative of the project's co-ordinator[1], Title and Organisation:

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Project website[2] address:

[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the grant agreement

[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm ; logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

4.1 Final publishable summary report

Beneficiaries: FAG Aerospace GmbH & Co. KG
Georg-Schaefer-Straße 30
97421 Schweinfurt

Introduction

The current planetary bearings including the surrounding components are designed according to pragmatic rules which are less and less relevant to the conditions predicted for the next generation of engine concepts and the related power gearbox requirements because of higher torque density, more severe working conditions, higher temperatures and simultaneously reduced weight. These resulting overall gearbox requirements together with the need for reduced weight lead finally to drastically increased load and speed conditions for the planetary bearings which can not be compensated by increasing the bearing dimensions. With current bearing designs, materials and analytical tools the requirements on life capability, reliability and contamination resistance cannot be sufficiently met and are way above existing applications and experiences. Therefore it is necessary to improve the surface and near surface robustness in the contact areas of planet bearing systems to take full advantage of the material inherent life potential without taken the risk of surface initiated premature system failures.

To overcome these problems, the following main RTD activities are a necessity:

1. New, improved and more durable materials and material processing technologies in order to increase
    - component life under high load and speed
    - wear resistance under contamination and boundary lubrication

2. New and verified stress and life analysis methods to fully consider the improved material capabilities

Design Study of Advanced Planet Bearing

In the preliminary design study the selection criteria for advanced bearing design / technologies and the required material characteristics was defined to meet the requirements of

- extended bearing life under
    - high load
    - oil contamination
    - wear conditions

A planet bearing design study was performed. The bearings, subject of this study, shall be applied in the planetary stage of future aircraft engine gearboxes. Such gearboxes shall provide a higher power density at minimum weight and improved operational reliability than state-of-the-art gearboxes which in parallel means for the associated bearings higher load, speed and live capabilities.
Therefore the design study was considering the following aspects:

- Suitable types of bearings
- Detailed analytical investigation and calculation
- Potential bearing and gear materials

The specific operating conditions with regard to speed, load, centrifugal forces and mesh forces were analysed and calculated.

Technology Development

Two different materials were identified for the test campaign. Ferrium C61 is an innovative high strength steel and M50NiL (high speed tool steel) as Baseline, because it is the state of the art material for aerospace bearings.

The material characteristics of Ferrium C61 as lined out in the material data sheet are very promising to fulfil the requirements of planetary bearings, because of the following aspects:

- very high fracture toughness of > 140 MPa√m
- high tensile and yield strength
- high core hardness of 47 – 50 HRC
- good surface hardness of 60 – 62 HRC
- possibility of plasma nitriding to increase the surface hardness
- good thermal stability

There are two different requirements on the properties regarding the case hardness profiles of gears and bearings.

The heat treat processes for M50NiL and Ferrium C61 were investigated and the process parameters were optimised to achieve the desired surface hardness and case depth. Many heat treat tests using gas carburizing, plasma nitriding and gas nitriding procedures were processed and analysed to find the optimal process parameters.

For the hardware tested in this project a special heat treating procedure was developed. This procedure consists of low pressure carburizing, vacuum hardening and tempering. **Figure 1** shows typical hardness profiles and a micrograph of the carburized case of Ferrium C61 heat treated with this process. The process details are AVIO proprietary.

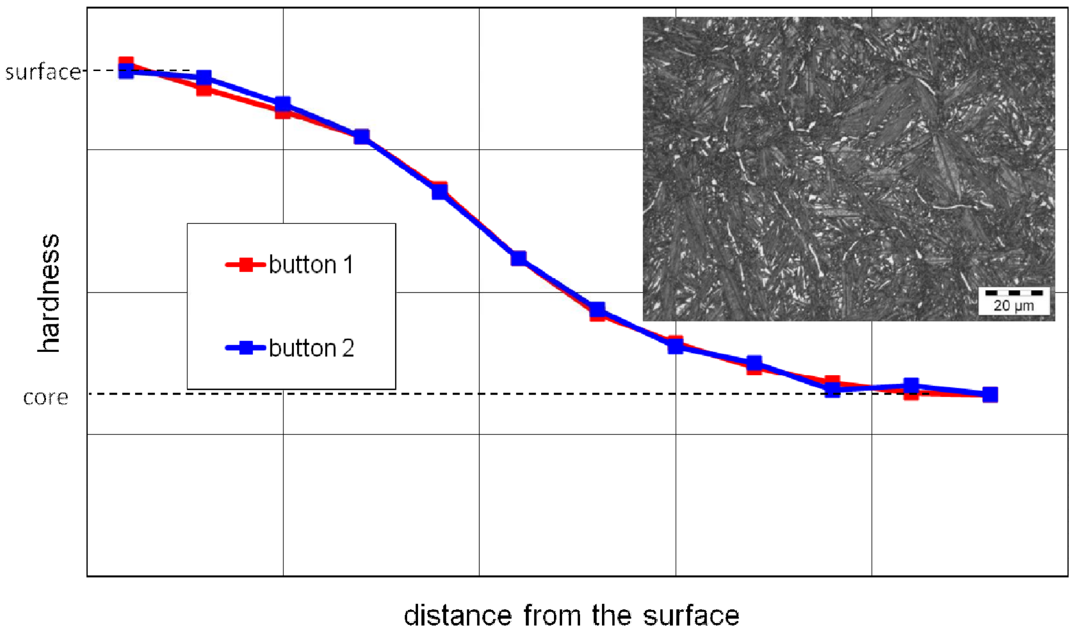

Figure 1: Hardness Profiles and microstructure of two specimens (discs), Ferrium C61 carburized and hardened

The microstructure looks good, no carbide network, the carburized layer is uniform, no marked variation in case depth. **Figure 2** shows a residual stress profile of one disc. The stress profile shows residual compressive stress which is typical for a carburized layer.

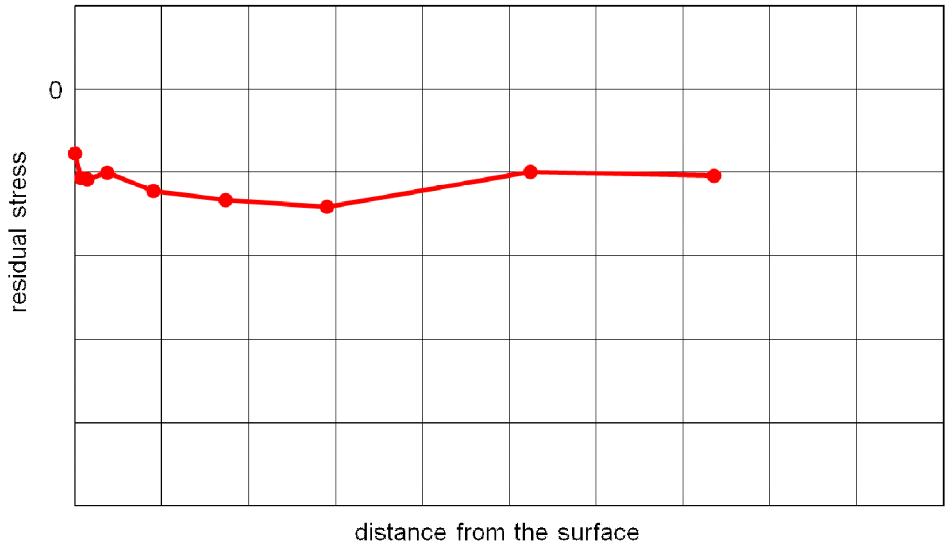

Figure 2: Residual stress profile of a specimen (disc) Ferrium C61 carburized and hardened

A part of the test hardware should be nitrided in order to increase fatigue life under severe conditions. Typical nitriding processes are performed at temperatures above 500°C, Ferrium C61 is sensitive against tempering above 500°C, therefore a study was performed to show the limit of the nitriding temperature of Ferrium C61. For this, specimen of Ferrium C61 were carburized, hardened and exposed to annealing cycles in protective atmosphere at several temperatures, each for a duration of t_1. This should simulate a nitriding process at the respective temperature. **Figure 3** shows hardness profiles of the carburized case after different annealing cycles. Only after annealing temperatures of T1 and T2 no significant reduction in hardness is visible. This means, that the nitriding temperature for Ferrium C61 should not exceed T2. As the diffusion rate of nitrogen is comparatively low at this temperatures, either the nitriding depth is low or a long cycle time is necessary.

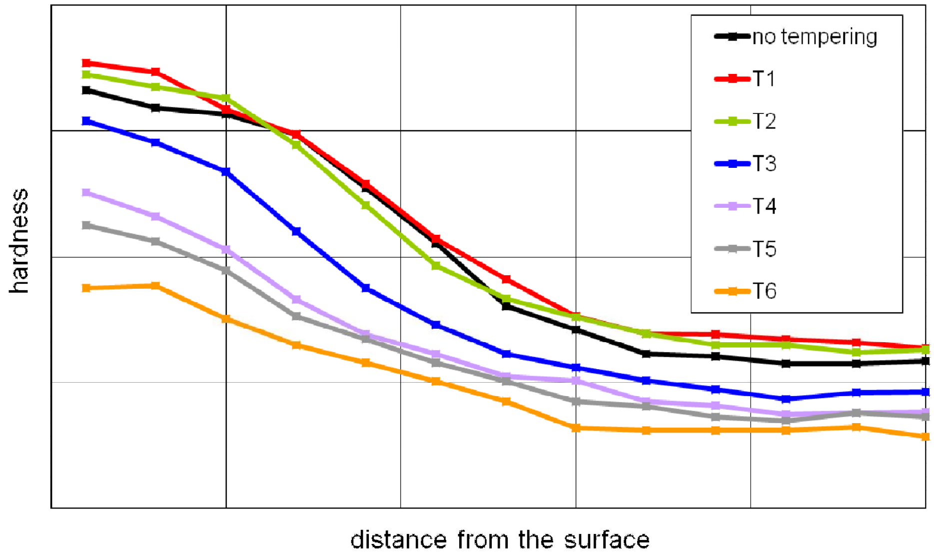

Figure 3: Hardness profiles of specimens Ferrium C61, carburized and hardened after annealing at different temperatures (T1<T2<T3<T4<T5<T6) (duration each t_1)

Figure 4 shows hardness profiles of Ferrium C61 after plasmanitriding and gasnitriding. In general the nitriding depth is low due to the low nitriding temperature. The hardness measurement after nitriding was done with an indenter load of 300gf (HV 0.3) in order to get a tighter spacing of the indentations and a lower distance of the first indentation to the surface.

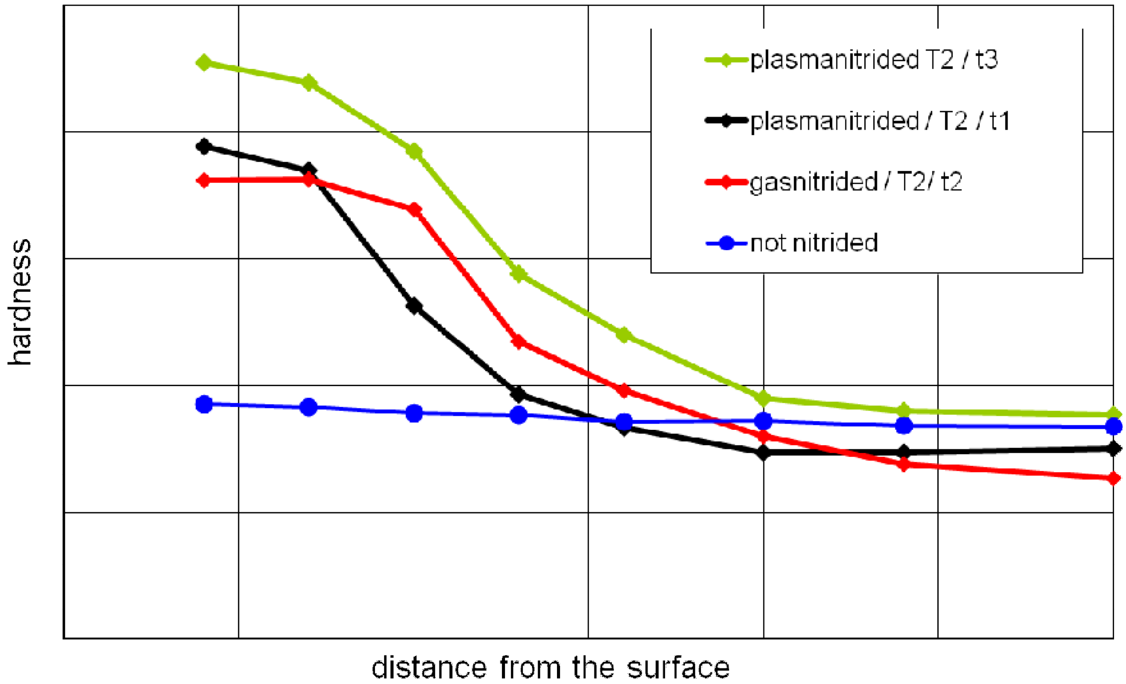

Figure 4: Hardness profiles of specimens, Ferrium C61, carburized and hardened after different nitriding cycles, the content of nitrogen in the process gas was different in the plasma nitriding cycles ($t_1<t_2<t_3$)

Figure 5 to 7 show the microstructure of the nitrided layer of all three nitriding variants. In case of the gas nitrided specimen there are marked precipitates at the grain boundaries and slight formations of a white layer on the surface.

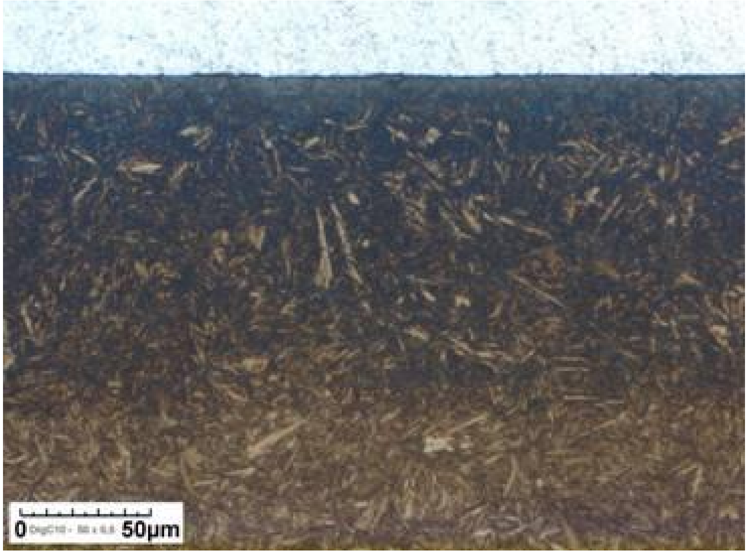

Figure 5: Microstructure of Ferrium C61, carburized, hardened and plasmanitrided (T2/t3)

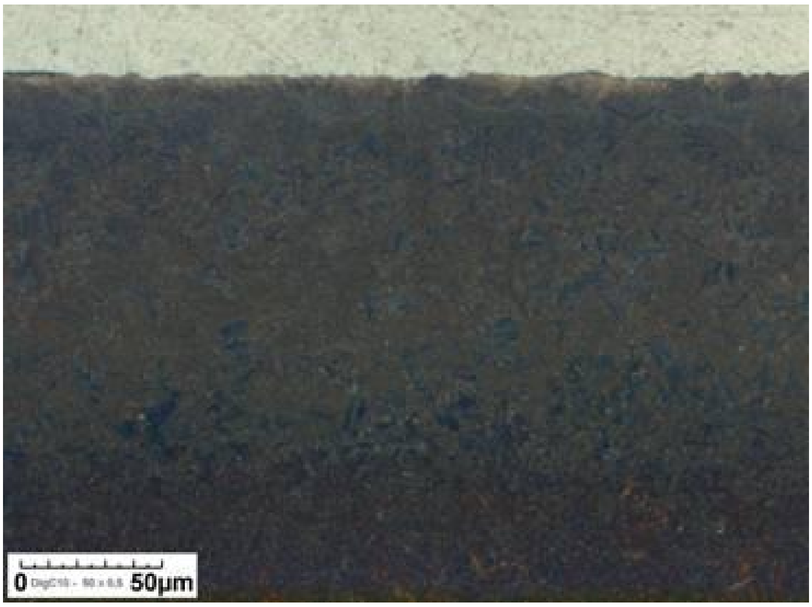

Figure 6: Microstructure of Ferrium C61, carburized, hardened and plasmanitrided (T2/t_1)

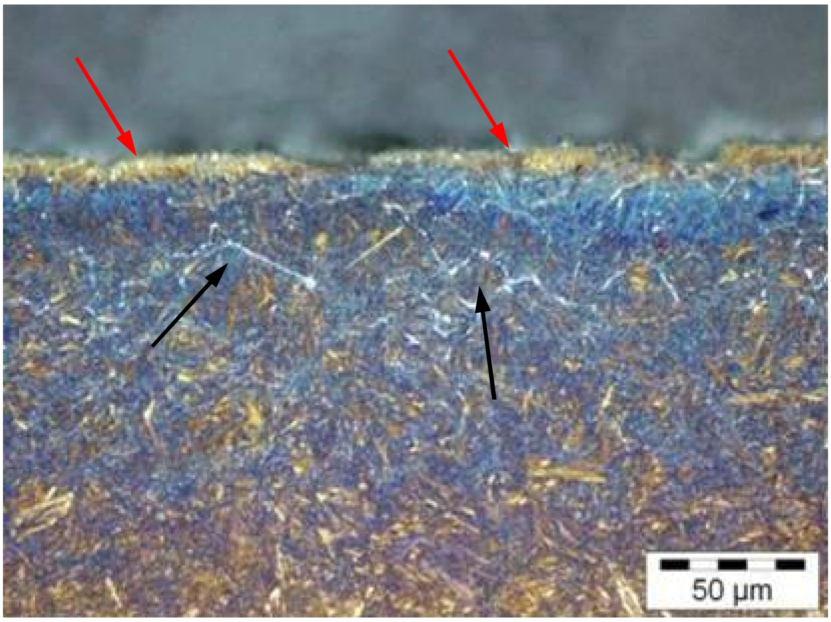

Figure 7: Microstructure of Ferrium C61, carburized, hardened and gas nitrided (T2/t_2) IGNs (black arrows), white layer (red arrows)

For nitriding of the test hardware (small scale test bearing IRs) the plasma nitriding process with a cycle time t_3 was applied (t_3>t_2>t_1).
The evaluation results of these test bearing IRs are shown in **Figure 8** (hardness profiles) and **Figure 9** (microstructure).

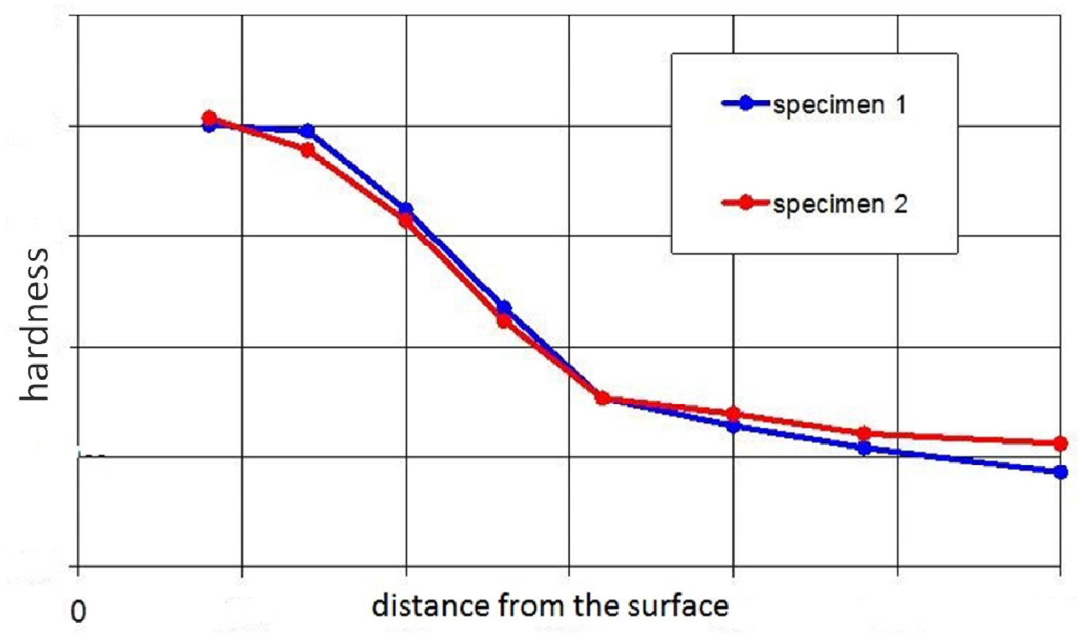

Figure 8: Hardness profiles of test bearing IRs, Ferrium C61, carburized, hardened and plasmanitrided (T2/t_3)

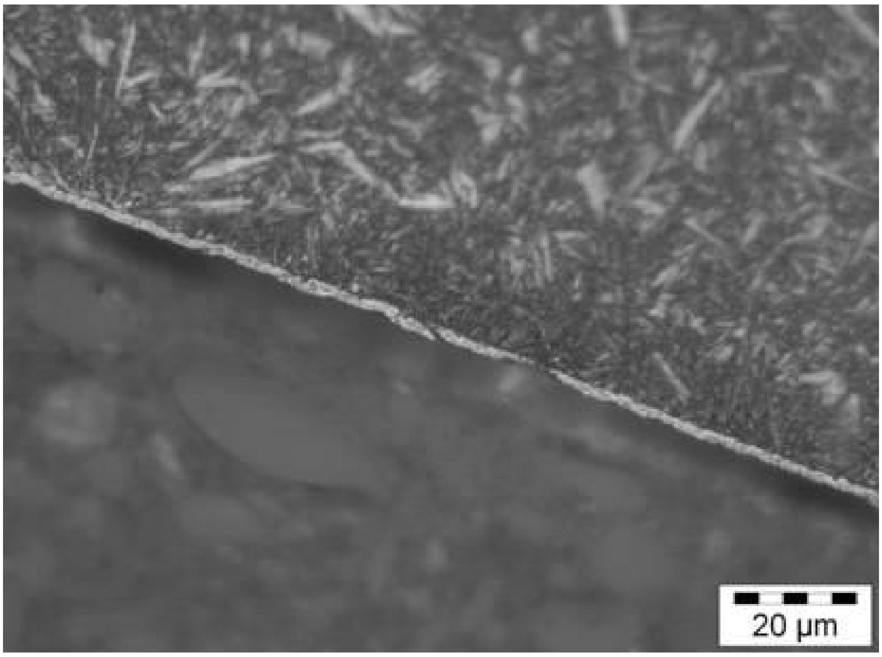

Figure 9: Microstructure of test bearing IRs, Ferrium C61, carburized, hardened and plasmanitrided (T2/t_3)
slight white layer but no IGNs

Test Plan

A test plan (consisting of 3 different tests: Endurance, contamination and spall propagation) was developed to substantiate bearing life improvement and applicability to gears. The endurance tests were performed under low lambda conditions, which can occur during operation. The contamination tests are running with pre-damaged inner rings caused by a HRC indenter. For the spall propagation tests the spalled bearings of the contamination tests are used under a reduced pressure. The spall propagation is monitored several times (depending on the propagation speed) until 20% of the inner ring circumference is spalled.

M50NiL plasma nitrided rings were used as the Baseline, since numerous previous test series had shown that plasma nitrided M50NiL bearing components provided the highest fatigue limit for bearings compared to the standard materials in use for aerospace applications.

Endurance Testing

In the following table the test results of Endurance test under mixed lubrication are shown:

Material	Bearings tested	IR failures	B_{10} life*	Weibull slope
M50NiL-DH	12	6	746x	3,88
Ferrium C61	13	8	9x	0,51
Ferrium C61-DH	13	6	1x	1,10

* referenced to the calculated life according to DINISO 281

The slope of the partial regression line is very smooth and reaches only a β-value of 0,51 for Ferrium C61. If the β-value is smaller than 1 it is usually an indication for an unsteady process leading to infant mortality. In the case of wear and fatigue a β-value bigger than 1 was expected, as it was determined in the M50Nil-DH testing (β = 3,88). The plasma nitriding of Ferrium C61 was resulting even in a deterioration of the life time capability of Ferrium C61.
Some of the Ferrium C61 bearings showed a long running time without a failure, indications that Ferrium C61 has basically potential for good performance under mixed lubrication conditions.

For remaining parts, investigation performed indicated an infant mortality issue related to an early melting practice and a possible improvement of the carburising process.

Therefore further tests with improved material (of the latest melting practise) and improved heat treatment process of Ferrium C61 were performed.

In the following table the test results of Endurance test under mixed lubrication are shown:

Material	Bearings tested	IR failures	B_{10} life*	Weibull slope
Ferrium C61 (old)	13	8	9x	0,51
Ferrium C61 (new)	12	7	7x	0,51

* referenced to the calculated life according to DINISO 281

The repetition test of Ferrium C61 with the optimised heat treatment and material of the latest melting practise showed no life time improvement at all. The Weibull curve is a duplicate of the previous test. The implemented modifications were not appropriate to improve the capability of Ferrium C61.

Due to the fact of the infant mortality of Ferrium C61 a second endurance test under full lubrication conditions should clarify whether we have surface initiated or subsurface initiated failures. The test bearings were from the same manufacturing lot as used for the endurance test under mixed lubrication.

In the following table the test results of Endurance test under mixed and full lubrication are shown:

Material	Bearings tested	IR failures	B_{10} life*	Weibull slope
Ferrium C61 (mixed lubrication)	12	7	7x	0,51
Ferrium C61 (full lubrication)	6	3	1x	0,42

* referenced to the calculated life according to DINISO 281

Both Weibull curves are almost identical and are characterized by a very smooth slope. The use of full lubrication conditions did not show any improvement compared to the mixed lubrication conditions. This is a strong indication that we are faced with subsurface fatigue instead of surface initiated fatigue.

In the literature a hind could be found that high cobalt based high strength steels show a poor rolling contact fatigue behavior. In Erwin Zaretsky's book "Tribology for Aerospace Applications, page 343f " only this statement can be found, but an explanation of the reason is missing.

The contamination test was only performed with the Baseline Material M50Nil-DH because of the not yet satisfying results of Ferrium C61 and Ferrium C61-DH in the endurance testing. These tests will be performed when Ferrium C61 material of better quality is available. The bearing test campaign was performed with 12 bearings. The maximum test time was fixed until an inner ring spall occurs (apart high running time tests which were suspended).

Contamination Testing

The contamination test was only performed with the Baseline Material M50Nil-DH because of the poor results of Ferrium C61 and Ferrium C61-DH in the endurance testing. The bearing test campaign was performed with 12 bearings. The maximum test time was fixed until an inner ring spall occurs (apart high running time tests which were suspended).

The pre-damaging of the inner rings was performed by a modified Rockwell indenter. In total 8 HRC indents with different angles (19,2° to 41,6°) distributed over the whole running track circumference were inserted in the inner ring (see **figure 10**). The indent size was fixed to a diameter of 160 µm.

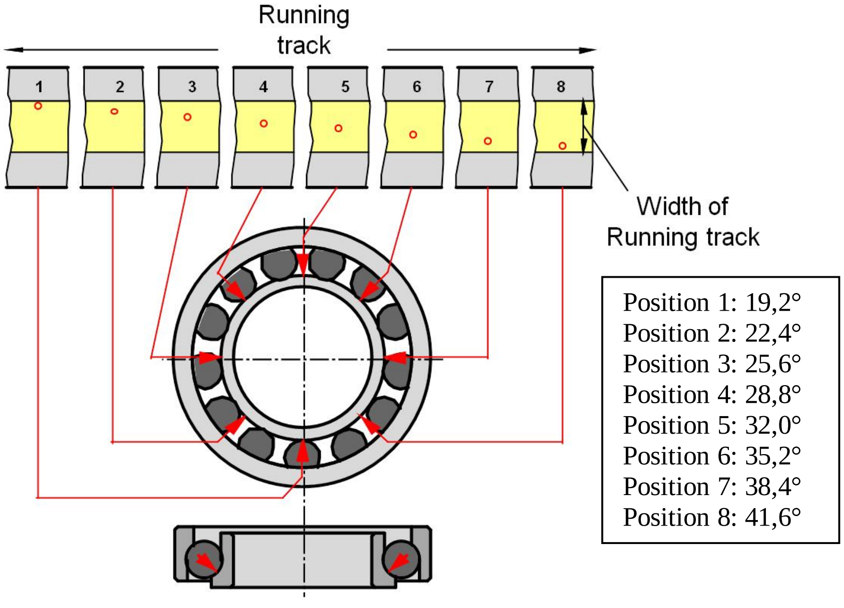

Figure 10: Indentation pattern on inner ring raceway

In the following table the test results of contamination test are shown:

Material	Bearings tested	IR failures	B_{10} life*	Weibull slope
M50NiL-DH	12	11	10x	1,23

* referenced to the calculated life without considering the influence of contamination

All failed parts showed a typical inner ring pitting at position 1 (19,2°) to position 4 (28,8°), as it was expected. All other components (balls, outer ring and cage) showed no failures. This contamination test will be used as the Baseline for further high strength material development for bearings.

Spall Propagation Testing

The failed bearings of the contamination test were used to show the spall propagation behaviour of M50NiL-DH. The initial spall size after the Contamination Test was documented and determined by microscope (**figure 11**).

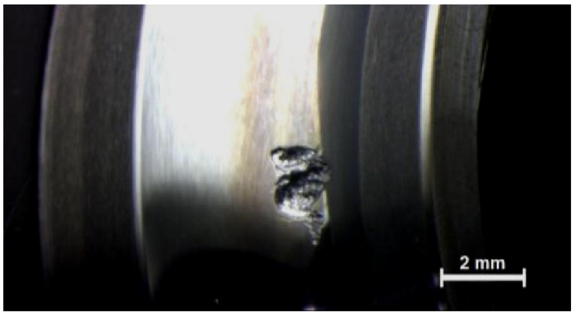

Figure 11: Example of Initial spall size after contamination test

The spall propagation was documented after several hours depending on the propagation speed of the inner ring. The shut down of the test rig was regulated by the vibration signal. The threshold was set to a 10% vibration increase based on vibration level starting the test. The goal was to generate at least 3 to 4 data point for each test bearing.

Each spall propagation test was continued until 20% of the raceway circumference was spalled. In **figure 12** an overview of the spall propagation results of the material M50NiL-DH is shown.

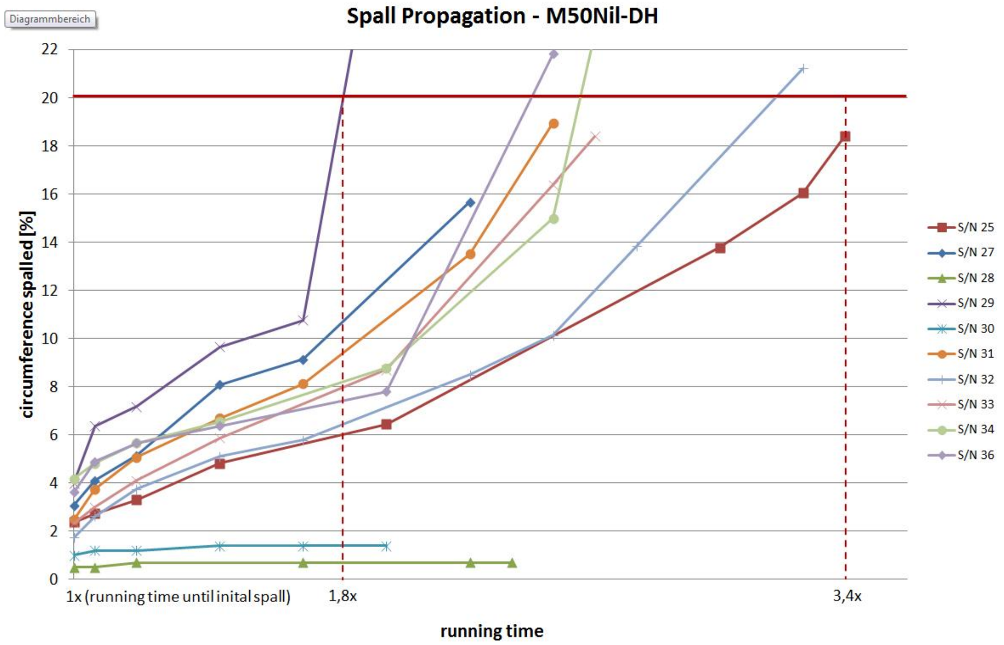

Figure 12: Spall Propagation Behaviour of M50NiL-DH material

The limit of “20% of the circumference is spalled” is reached between additional 0,8x to 2,4x of the running time the initial spall occurred. It is obvious that the initial spall size influence the spall propagation speed. If the initial spall is below a certain size (in this case smaller than 1% of the circumference) no spall propagation can be observed. The dwell point lies between 6% to 10% spalled area of the circumference. If this failure size is reached, the propagation speed is accelerated immediately, because 2 rolling elements are in contact with the failed raceway at the same time. This spall propagation test will be used as the Baseline for further high strength material development for bearings.

Conclusion

Also by various steps to improve the melting procedure for the base material and various improvements for the applied heat treatment the test results gained still showed not sufficient results for the high demanding application. A fishbone diagram was used to investigate the failure root cause and all potential root causes were investigated. These investigations let to certain improvements with regard to the achieved material properties but were not satisfying the application. Potentially nitriding heat treatment could be beneficial but performed trials did not reach the required depth.

The M50NiL-DH material showed a very good performance at the endurance, contamination and spall propagation test. No sudden ring failure could be observed. The spall propagation speed is dependent on the initial spall size. In average additional 0,8x to 2,4x of the running time until the initial spall occurred, could be reached until 20% of ring circumference is spalled. Nevertheless, these results serve as a very profitable Baseline for further material and heat treatment studies and developments.

4.2 Use and dissemination of foreground

Section A (public)

The results of the project should initially be exploited at an early stage by application to current development projects as a demonstration and test of the new design and materials technologies. It was planned that the technology acquired would be fully utilised in new commercial aero-engines (e.g. CROR). Due to the non satisfying performance of Ferrium C61 as a new high strength material for planetary bearings, it was decided not to disseminate the results in publications, conferences or flyers. The very promising results of M50NiL-DH and the improvement on the characterisation process and on the knowledge of the material properties are considered highly sensitive information and can not therefore be published. All other information regarding the material treatment and properties were already disseminated in various publications, conferences and flyers over the past years.

TEMPLATE A: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[3] (if available)	Is/Will open access[4] provided to this publication?
1	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*		
2										
3										

[3] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).
[4] Open Access is defined as free of charge access for anyone via the internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

Section B (confidential)

The plasma nitriding and gas nitriding of M50NiL was patented several years ago. Because the carburizing and the gas and plasma nitriding processes of Ferrium C61 did not lead to the expected results regarding rolling contact fatigue, it was decided not to apply for a patent for these technologies.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.

Type of IP Rights: Patents, Trademarks, Registered designs, Utility models, etc.	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
n/a	n/a	n/a	n/a

TEMPLATE B2: OVERVIEW TABLE WITH EXPLOITABLE FOREGROUND

Exploitable Foreground (description)	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
n/a	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*

4.3 Report on societal implications

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	**CS-GA-2009-255034**
Title of Project:	**Power Gear Box (PGB) advanced planet bearings**
Name and Title of Coordinator:	**Edgar Streit**

B Ethics		
1. Did you have ethicists or others with specific experience of ethical issues involved in the project?	O **X**	**Yes** **No**
2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***	
INFORMED CONSENT		
• Did the project involve children?		
• Did the project involve patients or persons not able to give consent?		
• Did the project involve adult healthy volunteers?		
• Did the project involve Human Genetic Material?		
• Did the project involve Human biological samples?		
• Did the project involve Human data collection?		
RESEARCH ON HUMAN EMBRYO/FOETUS		
• Did the project involve Human Embryos?		
• Did the project involve Human Foetal Tissue / Cells?		
• Did the project involve Human Embryonic Stem Cells?		
PRIVACY		
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)		
• Did the project involve tracking the location or observation of people?		
RESEARCH ON ANIMALS		
• Did the project involve research on animals?		
• Were those animals transgenic small laboratory animals?		
• Were those animals transgenic farm animals?		
• Were those animals cloning farm animals?		
• Were those animals non-human primates?		
RESEARCH INVOLVING DEVELOPING COUNTRIES		
• Use of local resources (genetic, animal, plant etc)		
• Benefit to local community (capacity building ie access to healthcare, education etc)		
DUAL USE		
• Research having potential military / terrorist application		

C Workforce Statistics

3 Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	**Number of Women**	**Number of Men**
Scientific Coordinator		2
Work package leader	5	2
Experienced researcher (i.e. PhD holders)		1
PhD Students		

Other		

4 How many additional researchers (in companies and universities) were recruited specifically for this project?	**none**
Of which, indicate the number of men:	
Of which, indicate the number of women:	

D Gender Aspects

5	**Did you carry out specific Gender Equality Actions under the project** ?	O X	Yes No

6 Which of the following actions did you carry out and how effective were they?

		Not at all effective				Very effective
❑	Design and implement an equal opportunity policy	O	O	O	O	O
❑	Set targets to achieve a gender balance in the workforce	O	O	O	O	O
❑	Organise conferences and workshops on gender	O	O	O	O	O
❑	Actions to improve work-life balance	O	O	O	O	O
O	Other:					

7 Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

- O Yes- please specify
- X No

E Synergies with Science Education

8 Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

- O Yes- please specify
- X No

9 Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

- O Yes- please specify
- X No

F Interdisciplinarity

10 Which disciplines (see list below) are involved in your project?

- X Main discipline[5]: 2.3 metallurgical and materials engineering
- O Associated discipline[5]:
- O Associated discipline[5]:

G Engaging with Civil society and policy makers

11a	**Did your project engage with societal actors beyond the research community?** *(if 'No', go to Question 14)*	O X	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

- O No
- O Yes- in determining what research should be performed
- O Yes - in implementing the research
- O Yes, in communicating /disseminating / using the results of the project

[5] Insert number from list below (Frascati Manual)

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ○	Yes No

12 Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ○ International level

H Use and dissemination	
14 How many Articles were published/accepted for publication in peer-reviewed journals?	**none**
To how many of these is open access[6] provided?	**none**
How many of these are published in open access journals?	**none**
How many of these are published in open repositories?	**none**
To how many of these is open access not provided?	**none**
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other: ……………	

15 How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**none**

16 Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**none**
	Registered design	**none**
	Other	

17 How many spin-off companies were created / are planned as a direct result of the project?	**none**
Indicate the approximate number of additional jobs in these companies:	

18 Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

❑	Increase in employment, or	❑	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	X	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify	❑	

19 For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	X

[6] Open Access is defined as free of charge access for anyone via the internet.

I Media and Communication to the general public

20 As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes X No

21 As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes X No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

❑	Press Release	❑	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
❑	Brochures /posters / flyers	❑	Website for the general public / internet
❑	DVD /Film /Multimedia	❑	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	X	English
❑	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)
3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES
4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)
4.2 Veterinary medicine

5. SOCIAL SCIENCES
5.1 Psychology
5.2 Economics
5.3 Educational sciences (education and training and other allied subjects)
5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES
6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)
6.2 Languages and literature (ancient and modern)
6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group] .