

BGA PROJECT 11

Materials for Enhanced Gear Fatigue Performance

DRAFT PROPOSAL (Version 2, September 2009)

INTRODUCTION

This draft proposal details work discussed as follow-on topics for investigation from BGA Project 5 Phase 2 Parts B and C. Whilst these projects were previously run as separate projects (P5B as a BGA consortium project and P5C as a stand-alone consortium project), it is has been decided to move forward as a single, combined follow-on project.

The work proposed here aims to explore in more detail gear material developments that result in improved load carrying capacity and reliability whilst taking into consideration aspects of performance/cost benefits. The work proposed concentrates on evaluating gear tooth bending fatigue strength using single tooth pulsator testing as has been used in previous phases of the project. The variables to be investigated include the base steel type, heat treatment method and post heat treatment processing.

Specific topics included for investigation are:-

- 1) The benefits to be expected from vacuum carburising when using appropriate steel selection.
- 2) The possibilities for controlling the influence of IGO through either heat treatment or alloy selection.
- 3) The effect of increasing core strength for a nitrided steel.
- 4) Assessment of re-heat hardened AISI 9310 VAR and LESCO 53 VIM VAR for comparison with direct hardening data generated in Project 5 Phase 2 Part C.
- 5) Assessment of re-heat hardened air melt grades of AISI9310 and 18CrNiMo7 for comparison with direct hardened data already available from Project 5 Phase 2 Part C.
- 6) Methods to prevent end chamfer related failures in root ground gears linked to initiation from remaining IGO.
- 7) Assessment of an alternative nitriding steel to improve overload capacity.

1. WORK PACKAGE B/C3-1: VACUUM CARBURISED STEEL

1.1. SCOPE OF WORK

This work package will investigate the bending fatigue strength of vacuum carburised gears manufactured using a grade of steel selected by CES. For the results to be comparable with those generated previously, it is proposed that the test gears will be manufactured to the same geometrical specification as the vacuum carburised 16MnCr5 gears tested in BGA Project 5 Phase 2 Part B. The proposed test matrix for Work Package B/C3-1 is shown in Table 1.

Table 1: Proposed bending fatigue test matrix for Work Package B/C3-1.

Material	Heat treatment	Root condition	Number of gears
TBC	Vacuum carburised	Hobbed	6

1.2. COSTS

It is assumed that the material and heat treatment will be provided FOC by CES and Wallwork Heat Treatment Ltd respectively.

- Manufacture 6 pulsator test gears
- Metallurgical characterisation:
 - Micro-hardness profile and microstructural analysis
 - Retained austenite measurements (1 gear, 3 data points)
 - Residual stress measurements (1 gear, 8 data points)
- Metrology checks and root scans
- Pulsator testing:
 - Fixture setup and calibration
 - Staircase tests (≥ 40 data points)
 - Finite life tests (≥ 12 data points)
- Analysis and reporting:
 - Staircase analysis
 - Metrology interpretation and stress analysis
 - Uncertainty evaluation
 - SEM analysis of fracture surfaces

2. WORK PACKAGE B/C3-2: CONTROL OF INTERGRANULAR OXIDATION

2.1. SCOPE OF WORK

This work package will investigate the bending fatigue strength of gas carburised gears manufactured using Ovako 158Q steel and vacuum carburised gears manufactured using Ovako 277L steel. The data for the vacuum carburised Ovako 277L gears will be partly

taken from the X-GEAR project and will be provided by the BGA as in-kind support. X-GEAR data is available as a 20 point staircase with 6 finite life tests. Additional tests will be performed to increase this to a 40 point staircase with 12 finite life tests, in order to be consistent with other data sets being generated. The test gears will be manufactured to the same geometrical specification as the vacuum carburised gears tested in Work Package B/C3-1 and the proposed test matrix is shown in Table 2.

Table 2: Proposed bending fatigue test matrix for Work Package B/C3-2.

Material	Heat treatment	Root condition	Number of gears
Ovako 158Q	Gas carburised	Hobbed	6
Ovako 277L*	Vacuum carburised	Hobbed	5

* 20 staircase tests, 6 finite life tests available from X-GEAR

20 additional staircase and 6 finite life tests to be performed. Gears available from X-GEAR.

The above assumes that Ovako 158Q is agreed by the consortium as an appropriate steel to investigate where alloy chemistry is designed to limit IGO. Consortium partner steel producers have been asked to consider appropriate alternatives.

2.2. COSTS

It is assumed that the material and heat treatment will be provided FOC by Ovako Steel (or other if steel choice modified) and Wallwork Heat Treatment Ltd respectively.

- Manufacture 6 pulsator test gears
- Metallurgical characterisation:
 - Micro-hardness profile and microstructural analysis
 - Retained austenite measurements (3 data points)
 - Residual stress measurements (8 data points)
- Metrology checks and root scans
- Pulsator testing:
 - Fixture setup and calibration carried out as part of WP 3B/C-1
 - Staircase tests (≥ 40 data points)
 - Finite life tests (≥ 12 data points)
- Analysis and reporting:
 - Staircase analysis
 - Metrology interpretation and stress analysis
 - Uncertainty evaluation
 - SEM analysis of fracture surfaces

3. WORK PACKAGE B/C3-3: INCREASED CORE HARDNESS – NITRIDED STEEL

3.1. SCOPE OF WORK

This work package will investigate the effect of core hardness on the bending fatigue strength of gas nitrided gears manufactured using En40B steel. For the data to be comparable with that generated previously, it is proposed that the test gears will be manufactured to the same geometrical specification as the gas nitrided En40B gears tested in BGA Project 5 Phase 2 Part B. The proposed test matrix for Work Package B/C3-3 is shown in Table 3.

Table 3: Proposed bending fatigue test matrix for Work Package B/C3-3.

Material	Heat treatment	Root condition	Number of gears
En40B	Gas nitrided (core hardness TBC)	Hobbed	6

3.2. COSTS

It is assumed that the material and heat treatment will be provided FOC by CES and Wallwork Heat Treatment Ltd/Allen Gears respectively.

- Manufacture 6 pulsator test gears
- Metallurgical characterisation:
 - Micro-hardness profile and microstructural analysis
 - Residual stress measurements (10 data points)
- Metrology checks and root scans
- Pulsator testing:
 - Fixture setup and calibration
 - Staircase tests (≥ 40 data points)
 - Finite life tests (≥ 12 data points)
- Analysis and reporting:
 - Staircase analysis
 - Metrology interpretation and stress analysis
 - Uncertainty evaluation
 - SEM analysis of fracture surfaces

4. WORK PACKAGE B/C3-4: RE-HEAT HARDENED AISI 9310 VAR AND LESCO 53 VIM VAR

4.1. SCOPE OF WORK

This work package will investigate the bending fatigue strength of re-heat hardened, gas carburised gears manufactured from both AISI 9310 VAR and LESCO 53 VIM VAR steel to generate comparison data with previously tested gears in the direct hardened condition. The

gears will be manufactured to the same geometrical specification as the carburised gears tested in Project 5 Phase 2 Part C and the proposed test matrix is shown in Table 4.

Table 4: Proposed bending fatigue test matrix for Work Package B/C3-4.

Material	Heat treatment	Root condition	Number of gears
AISI9310 VAR	R-H harden	Ground	6
LESCO 53 VIM VAR	R-H Harden	Ground	6

4.2. COSTS

It is assumed that the material and heat treatment will be provided FOC by CES/Timken and Wallwork Heat Treatment Ltd respectively.

- Manufacture 12 pulsator test gears
- Metallurgical characterisation:
 - Micro-hardness profile and microstructural analysis
 - Retained austenite measurements (3 data points)
 - Residual stress measurements (8 data points)
- Metrology checks and root scans
- Pulsator testing:
 - Fixture setup and calibration
 - Staircase tests (≥ 40 data points)
 - Finite life tests (≥ 12 data points)
- Analysis and reporting:
 - Staircase analysis
 - Metrology interpretation and stress analysis
 - Uncertainty evaluation
 - SEM analysis of fracture surfaces

5. WORK PACKAGE B/C3-5: RE-HEAT HARDENED AIR MELT AISI 9310 AND 18CrNiMo7

5.1. SCOPE OF WORK

This work package will investigate the bending fatigue strength of re-heat hardened, gas carburised gears manufactured from Air Melt grades of AISI 9310 and 18CrNiMo7 steels to generate comparison data with previously tested gears in the direct hardened condition. The test gears will be manufactured to the same geometrical specification as the carburised gears tested in Project 5 Phase 2 Part C and the proposed test matrix is shown in Table 5.

Table 5: Proposed bending fatigue test matrix for Work Package B/C3-5.

Material	Heat treatment	Root condition	Number of gears
AISI9310	R-H harden	Ground	6
18CrNiMo7	R-H Harden	Ground	6

5.2. COSTS

It is assumed that the material and heat treatment will be provided FOC by CES/Timken and Wallwork Heat Treatment Ltd respectively.

- Manufacture 12 pulsator test gears
- Metallurgical characterisation:
 - Micro-hardness profile and microstructural analysis
 - Retained austenite measurements (3 data points)
 - Residual stress measurements (8 data points)
- Metrology checks and root scans
- Pulsator testing:
 - Fixture setup and calibration
 - Staircase tests (≥ 40 data points)
 - Finite life tests (≥ 12 data points)
- Analysis and reporting:
 - Staircase analysis
 - Metrology interpretation and stress analysis
 - Uncertainty evaluation
 - SEM analysis of fracture surfaces

6. WORK PACKAGE B/C3-6: PREVENTION OF CHAMFER FAILURES INITIATED FROM IGO PRODUCED DURING GAS CARBURISING

6.1. SCOPE OF WORK

This work package will investigate the bending fatigue strength of root ground gears treated to remove the detrimental effect of remnant IGO in end chamfers, as was identified in Project 5 Phase 2 Part C. For comparison with Phase 2 data, it is suggested that direct hardened, gas carburised gears manufactured from 18CrNiMo7 steel should be used, but depending on the final programme, this may change (e.g. to be a re-heat hardened version from WP B/C3-5). It is proposed that 2 methods are investigated as a possibilities to influence the detrimental chamfer effect; a) mechanical removal prior to root grinding, b) shot peening prior to root grinding. The test gears will be manufactured to the same geometrical specification as the test carburised gears tested in Project 5 Phase 2 Part C and the proposed test matrix is shown in Table 4.

Table 6: Proposed bending fatigue test matrix for Work Package B/C3-6.

Material	Chamfer treatment	Root condition	Number of gears
18CrNiMo7	Mechanical removal	Ground	6
18CrNiMo7	Shot peen	Ground	6

6.2. COSTS

It is assumed that the material and heat treatment will be provided FOC by CES and Wallwork Heat Treatment Ltd respectively. It is also assumed that MIC will provide shot peening FOC.

- Manufacture 12 pulsator test gears
- Metallurgical characterisation:
 - Micro-hardness profile and microstructural analysis
 - Retained austenite measurements (3 data points)
 - Residual stress measurements (8 data points)
- Metrology checks and root scans
- Pulsator testing:
 - Fixture setup and calibration
 - Staircase tests (≥ 40 data points)
 - Finite life tests (≥ 12 data points)
- Analysis and reporting:
 - Staircase analysis
 - Metrology interpretation and stress analysis
 - Uncertainty evaluation
 - SEM analysis of fracture surfaces

7. WORK PACKAGE B/C3-7: ALTERNATIVE NITRIDING STEEL WITH INCREASED OVERLOAD CAPACITY

7.1. SCOPE OF WORK

This work package will investigate the performance of an alternative nitriding steel with potential to improve overload capacity when compared to data generated in Project 5 Phase 2 Part B. For the data to be comparable with that generated previously, it is proposed that the test gears will be manufactured to the same geometrical specification as the gas nitrided En40B gears tested in BGA Project 5 Phase 2 Part B. The proposed test matrix for Work Package B/C3-7 is shown in Table 7.

Table 7: Proposed bending fatigue test matrix for Work Package B/C3-7.

Material	Heat treatment	Root condition	Number of gears
TBC	Gas nitrided	Hobbed	6

7.2. COSTS

It is assumed that the material and heat treatment will be provided FOC by CES/Timken and Wallwork Heat Treatment Ltd/Allen Gears respectively.

- Manufacture 6 pulsator test gears
- Metallurgical characterisation:
 - Micro-hardness profile and microstructural analysis
 - Residual stress measurements (10 data points)
- Metrology checks and root scans
- Pulsator testing:
 - Fixture setup and calibration
 - Staircase tests (≥ 40 data points)
 - Finite life tests (≥ 12 data points)
- Analysis and reporting:
 - Staircase analysis
 - Metrology interpretation and stress analysis
 - Uncertainty evaluation
 - SEM analysis of fracture surfaces

8. TOTAL PROJECT COST

- | | |
|------------------------------------------------|----------|
| • Work Package 3B/C-1 | £ 12,584 |
| • Work Package 3B/C-2 | £ 14,930 |
| • Work Package 3B/C-3 | £ 13,364 |
| • Work Package 3B/C-4 | £ 24,624 |
| • Work Package 3B/C-5 | £ 24,624 |
| • Work Package 3B/C-6 | £ 24,924 |
| • Work Package 3B/C-7 | £ 13,364 |
| • Preparation for and attendance at meetings | £ 9,000* |
| • Preparation of final report and presentation | £ 6,800 |

TOTAL COST **£144,214**

* Estimate of cost based upon 9 meetings. If meetings are held at DU and/or combined with other meetings, then this cost will be less.

Note: No costs included for Administration related activity outside Design Unit.

9. TIMESCALES

It is proposed that this project runs over a 3 year period. DU could start work on gear manufacture as soon as steel is made available with testing scheduled to start early in 2010.