Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 8 (2018) 14–23

Structural Integrity Procedia

www.elsevier.com/locate/procedia

AIAS 2017 International Conference on Stress Analysis, AIAS 2017, 6-9 September 2017, Pisa, Italy

# Austempered Ductile Iron (ADI) for gears: Contact and bending fatigue behavior

Franco Concli[a]*

[a]*Free University of Bolzano/Bozen, piazza Università 1, Bolzano 39100, Italy*

**Abstract**

Austempered Ductile Iron (ADI) represents an alternative solution for the manufacturing of the housing of small planetary gearboxes, with the gear teeth obtained directly on the housing itself: such solution combines a cost-effective process with the possibility of obtaining complex geometry of the case. With respect to most traditional solutions, by means of ADI the requirements of strength and accuracy of the gear teeth can be satisfied without an additional finishing step after the heat treatment: the teeth can be obtained by broaching and, thanks to the low distortion which can be granted by the austempering process, a subsequent finishing operation is not needed. For these reasons, ADI has been selected for the application to a family of small gearboxes for automation. Due to the limited experience and data available for such material, to improve the design and rating processes, a testing campaign has been performed. The aim was to obtain strength data for bending and contact fatigue, considering the specific manufacturing and heat treatment processes. The paper describes the test procedures adopted and the test results, which have been obtained on gears specimens by means of Single Tooth Fatigue (STF) and pitting tests on a FZG type bench respectively. The tests are supported by metallurgical investigations on the failed teeth, to describe and understand the failure mechanisms. The results are then compared with the data and the shape curves provided by the international standards.


Peer-review under responsibility of the Scientific Committee of AIAS 2017 International Conference on Stress Analysis

*Keywords:* Austempered ductile iron; gears; bending; pitting; fatigue; tests

* Corresponding author. Tel.: +39-0471-017748; fax: +39-0471-017009.
*E-mail address:* franco.concli@unibz.it

2452-3216 
Peer-review under responsibility of the Scientific Committee of AIAS 2017 International Conference on Stress Analysis
10.1016/j.prostr.2017.12.003

## 1. Introduction

Industrial planetary gearboxes used for automation require high torsional stiffness, low backlash and low tolerances to fulfil the requirements in terms of positioning accuracy (Concli (2016)). The housing is often manufactured in nodular cast iron, and the teeth of the ring gear manufactured in the casing by broaching. This ensures a cost-effective production process also for complex geometries of the casing. To meet the requirements of strength for the gear teeth a heat treatment is often required. To remove the distortions induced by the heat treatment, finishing operations are desired.

With the adoption of Austempered Ductile Iron (ADI), the requirements of strength and accuracy can be met without the final finishing operation: the teeth are manufactured by broaching and, thanks to the low distortion which can be granted by the austempering process, the subsequent finishing process is avoided.

The limited experience and available data for such class of materials have represented the main limitations to the large diffusion of ADI in the production of gears even if some applications can be found starting from the '80 (Vennemann et al. (1968), Ford (1968)).

A reliable estimation of the performances of a new material in terms of tooth root bending and contact fatigue resistance, can be obtained only performing tests on gear specimens. The use of data derived by standard specimens adapted to the gear rating would introduce a lot of uncertainties and hypotheses in the calculation method, with the unavoidable consequence that the performances rated would be only a rough estimation of the reality.

The Standard ISO 17804 (2005) provides bending and contact fatigue limits for ausferritic spheroidal graphite cast irons of different grades which could be used for design in combination with the curves for the life factors $Y_{NT}$ and $Z_{NT}$ (which practically define the shape of the S-N curve) to calculate the fatigue strength at different numbers of cycles (ISO 6336-5 (2003)), respectively for bending and pitting. Nevertheless, the ISO standards does not refer in an explicit way to ADI and the curves for different families of cast irons should be considered. The Information Sheet AGMA 939 (2005) provides bending fatigue and pitting limits, together with $Y_N$ and $Z_N$ factors specifically for ADI.

The analysis of the available data points out that the different existing standards provide:

- Different values of the limits and different dependency from the specific variant of the material and/or from other properties or other post treatment
- Different trends for the shape of the S-N curves
- Some shaded areas of scattering both for the values and for the trend of the S-N curves, and different assumptions concerning the region of the fatigue limit and the existence of the fatigue limit itself.

Based on the previous experiences of the author, which has performed and published several tests on gears materials (Gorla et al. (2017)), it can be stated that the fatigue strength of gears is influenced by many parameters that, combined, can determine large variations of the effective performances. In the context of the design of an innovative family of low backlash precision planetary gearboxes (Concli et al. (2017), Wehrle et al. (2017)) the performances of which must be granted accurately, a research program aimed at the experimental investigation of gear data has been conducted.

The test campaign has been performed on gear specimens representative of all the geometrical and technological properties of the real product, including the casting process, the tooth root geometry, the heat treatment, cutting and finishing processes and residual stresses.

The bending fatigue tests were performed with the STF (Single Tooth Fatigue) test method as shown in Gorla et al. (2012), while the pitting tests, for which the effective meshing condition must necessarily be reproduced, have been performed by means of an FZG type back-to-back test rig as shown by Gorla et al. (2014).