

Experimental Characterization of Surface Durability of Materials for Worm Gears

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ABSTRACT:

This paper presents the methodology used for testing materials with a worm gear set-up and with a disc-roller machine. Several experimental results are discussed and analysed.

A correlation between metallurgical analyses of the structure of bronzes and experimental observations of subsurface cracks is given.

On the subject of wear, a specific method of measurement is explained and results are described.

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1 INTRODUCTION

The admissible values for the same combination of two materials, such as Bronze/Steel, varies according to the author of the document (see references [2], [4], [6]). Also the method and precise conditions of the tests differs between them and in some cases is unknown. CETIM has thus manufactured three disc/roller simulators for testing combinations of materials used in worm gears.

The fatigue curves obtained will be introduced later in the analytical calculation methods for load capacities [3], [8], [9]. For each combination of materials tested it was decided to metallurgically analyse the structure of the different bronze types. Also the cracks within simulated test rollers were observed to try and explain the fatigue phenomenon of contact pressure on the bronze surface.

2 FATIGUE TESTS

2.1 Test description

The fatigue tests have been performed on a disc/roller simulator which reproduces the kinematic conditions particular to worm gears: a bronze roller represents the worm wheel and rolls and slides on a steel disc which represents the worm.

The two mobile axes are orthogonal and independently driven. The roller can be positioned anywhere on the surface of the disc. It is thus possible to simulate any contact segment with a choice of the applied load and of the slipping speed (in magnitude and direction).

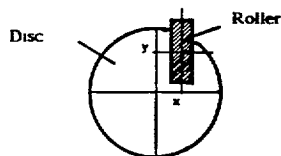


Fig. 1: Disc/roller contact

Over 20000 hours of tests have been completed. The final curves concerning the first bronze type (chilled cast UEI2P) have been drawn up. A few results have also been obtained for a second type : centrifugal UEI2P.

2.2 Test method

The geometry of the bronze rollers and the test conditions used are as follows:

GEOMETRY OF ROLLERS External radius: 49 mm Radius of crown: 250 mm Width: 18 or 25 mm	
TEST CONDITIONS Roller speed: 420 rpm Disc speed: 850 rpm Roller position: $x = 50$ $y = 34$ mm	

The geometry and test conditions have been determined so as to obtain pitting before 200 hours of testing on rollers submitted to average loads. No wear has been observed on rollers: the rolling track is formed very quickly when the disc contacts it and there is no width modification during test. Controls were undertaken before the tests to measure the crown and the external diameter of each roller. After the tests the width of the rolling track was also determined accurately.

The appearance, to the naked eye, of the first visible pitting was recorded whenever possible. In fact during tests with heavy loads, pitting evolves very quickly towards a large and unique scaling. However with rollers submitted to lower loads, very small size pittings appear on the periphery of the roller and evolve slowly. With the latter case a criteria to stop the test had to be set and was defined as the time when significant pitting of a least 2 mm in diameter appeared.

2.3 Examination of tests

Contact pressures are calculated in accordance with the Hertz model applied to a cylindrical type contact. In fact if the contact is at a point at the beginning of the test (due to the crowning), it evolves very quickly towards a cylindrical contact, the roller track being formed in a short time to the detriment of the crowning disappearance. The length of the cylinder in contact is taken account in the width of the track.

2.4 Material analysis

Disc: case hardened tempered: 35NCD16

Hardness: $H_{v125} = 750$

Rollers: Three types are available, all of the same grade: UEI2P, but obtained by different methods of manufacture. The hardness is given in the following chart:

SAND CAST	103,33 Hb
CHILLED CAST	108,07 Hb
CENTRIFUGAL	110,44 Hb

2.5 Results obtained

2.5.1 UEI2P chill cast bronze

14.000 hours of testing on 35 rollers have been required to set out the fatigue curve for this grade (figure 2). The longest test lasted 41 million cycles while the roller was submitted to a pressure of 344MPa. The roller with the heaviest load (671 MPa) produced scaling after 0,8 million cycles. The envelope curves give an off-set of 150 MPa.

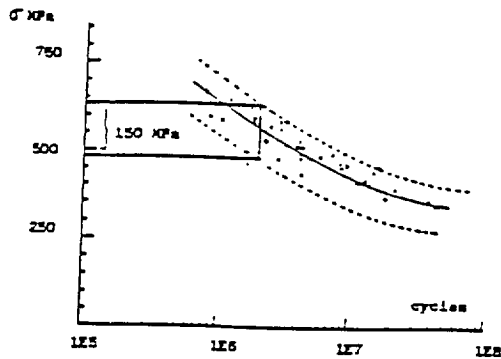


Fig. 2 : UEI2P chill cast bronze

The lower curve in figure 3 represents the appearance of the first visible pitting, the upper curve corresponds to the appearance of the scaling. It was only possible to record the first pitting after 10 million cycles. Below this value, the evolution of the pit is too quick (see the end of paragraph 2.2)

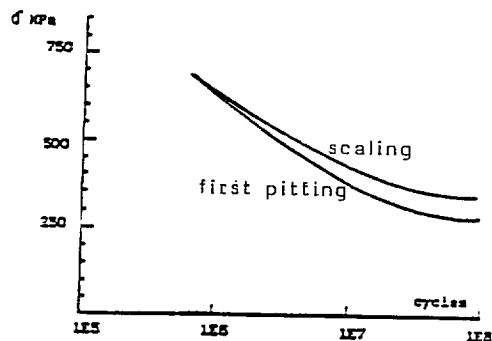


Fig. 3: UEI2P chill cast fatigue curve

2.5.2 UEI2P centrifugal bronze

At CETIM the new test benches, that permit the application of heavier loads, have allowed results concerning this grade to be supplied. An off-set of 150 MPa in relation to the scaling curve of UEI2P chill cast bronze is observed. All the pits obtained were singular and large.

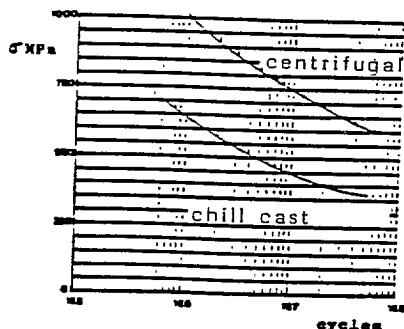


Fig. 4: Fatigue curves for UEI2P centrifugal bronze

2.5.3 Verification on actual gear-boxes

In order to validate the analytical method for the load capacity calculation, it should be noted that tests on two worm gears reducers were undertaken in parallel. For both the center distance was fixed to 125mm with a gear ratio of 1/40 for one and 1/31 for the other.

The materials chosen were identical to those tested in the disc/roller simulator. The endurance of these gears allowed confirmation of the results obtained for rollers.

3 METALLURGICAL ANALYSIS

3.1 Introduction

The analysis made of the two rollers tested on the simulator (chill casting and centrifugal) had two aims. The first was to observe the structure of the three different types of bronze to try and predict their behavior to fatigue and the second was to interpret the structural effects of fatigue due to the surface pressure. These different analysis were made at the ECAM Metallurgy Laboratory under the supervision of Mr P. COUV RAT.

3.2 Structural observations of the different types of bronzes

SAND CAST

In this case the cooling of the bronze during its solidification is slow. The process of solidification starts by the formation of SSα "germs" followed by their growth. A heterogeneous structure formed of dendrites is then obtained. Between these dendrites, the remaining liquid provides the eutectoid component.

The first tests made on this grade did not produce conclusive results. In fact the rolling track did not stabilize and had a tendency to occupy the whole width of the roller in a very short time, even when the roller was submitted to light loads.

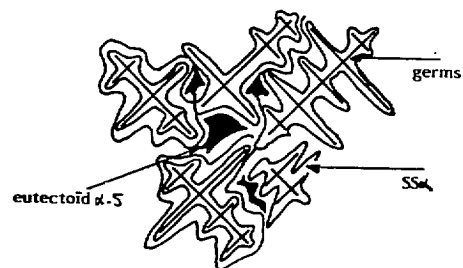


Fig. 5: Structure of the bronze

UEI2P CHILL CAST BRONZE

Castings in metallic moulds have a quicker cooling process those in sand casting with germination and dendrite formation. The grains obtained are of greater dimension and have little homogeneous structure. On the other hand a greater quantity of eutectoid α - δ is observed between the SSα grains. It is the hard and fragile eutectoid that