Ultrasonic fatigue testing of hardmetals in the gigacycle regime
Stage 1

Presentation of the Project

Abstract

In a first preliminary study, the application of ultrasonic resonance fatigue testing, as available in Vienna, for gigacycle fatigue testing of hardmetals is to be studied on 2 widely different hardmetal grades. Tentative S-N curves and fatigue endurance data at 10E10 cycles will be determined, and first information about crack initiation sites will be obtained. Further measurements and characterisations like measurement of residual stresses, microstructural characterisation of damage and fractographic investigations are also planned.

Introduction

Fatigue loading is also a very common phenomenon in tool materials; in addition to oscillating mechanical loads, cyclic thermal loading also adversely affects the materials to a large extent through mechanical effects. Although the loading cycle numbers in tooling applications are usually not up to the gigacycle range, extending the N range enables identifying fatigue effects much more clearly.

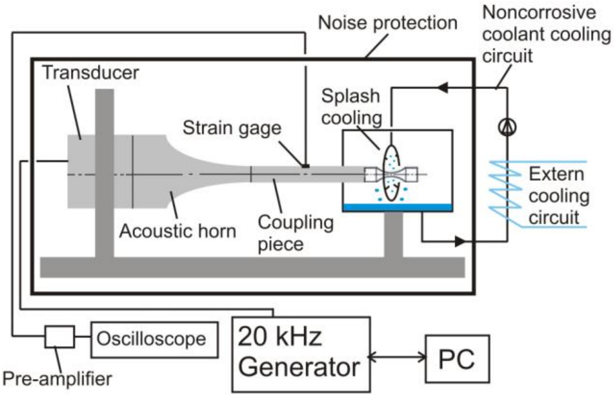
This holds particularly for the role of microstructural singularities, e.g. defects such as pores, inclusions etc.; gigacycle fatigue loading has therefore been introduced in the testing of high strength structural steels (for bearings, springs etc) since it is virtually the only method of revealing the last few small inclusions. For tool materials, carbide clusters or single larger carbides can also be detected; in hardmetals e.g. Co “pools”, larger carbide crystals or cubic carbide nests might be regarded as similar crack-initiating defects.

For hardmetals, one very relevant question is the role of the binder ligaments on toughness, in particular ligament thickness. Ligament bridging is more effective for improving the toughness in static than in cyclic loading, due to the very strong fatigue sensitivity of metals. This should stand out still more clearly if gigacycle fatigue testing is performed since it has been shown that in the gigacycle regime, strength concepts known from ceramics in static loading are highly applicable for ductile metals as well.

Ultrasonic fatigue testing of very hard and brittle materials:

Fatigue testing of brittle materials is notoriously tricky, in particular if reasonable volumes are to be tested. Standard servohydraulic testing requires extremely precise axial alignment of both testing machine and specimens, which is possible, but which is difficult to do in practice. Therefore, brittle materials are mostly tested in bending, which means however, that the nominally stressed volume is relatively small; this is a marked disadvantage if defect-controlled fatigue is to be expected.

Ultrasonic resonance testing avoids both problems since the specimens are loaded in push-pull – thus enabling reasonably large loaded volumes – while they are fixed on one end only, the other one resonating freely (see Fig.1). Slight deviations from axiality are easily tolerated by the system. This has been shown by the FWF project P17650-N02 (just finished): tool steels with hardness levels up to 67 HRC have been successfully tested; valuable information about clamping of the specimens to the resonance tester has been collected. A typical specimen shape is given in Fig.2.



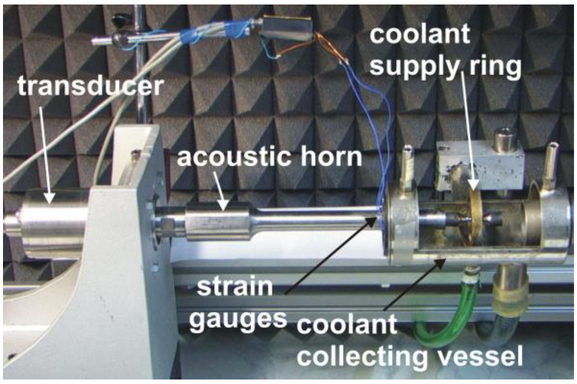


Fig.1: Ultrasonic resonance fatigue tester for gigacycle fatigue testing

A further, very significant advantage of the ultrasonic system is the dramatic reduction of testing time: 10E10 cycles can be attained within a few days; at standard test frequencies this would take 8-10 years. The fast accumulation of high loading cycle numbers also offers advantages when determining the threshold stress intensity factor: at da/dN = 10E-10 m/cycle the growth rate is 2 µm/s, i.e. a rate that can be easily tracked and recorded under the microscope in short time, which yields real threshold data.

An essential feature of the test system is cooling: damping effects result in specimen heating, in particular at the high stress amplitudes applied to high strength materials. To prevent this, secondary effect liquid cooling has been used successfully (Fig.1), corrosion and cavitation effects also being prevented by suitable measures.

Further measurements and characterisations should also be undertaken during the project:

- Measurement of residual stresses on gigacycle fatigue test samples
- Fractographic investigations
- Microstructural characterisation of damage during or after fatigue tests
- Grain size and distribution plus backup fractography

Possible secondary effects are then assessed to guarantee as much as possible the quality of the results.

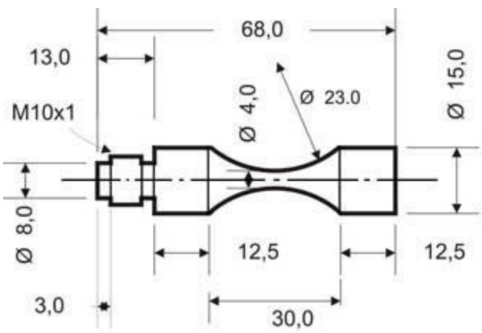


Fig.2: Shape of specimens used for gigacycle fatigue testing of tool steels (cold work steels and high speed steels)

<u>If you are interested in the project please sign and return to the EPMA the following Consortium Agreement.</u>

<u>If you are not an EPMA member or would like more information please contact Dr Olivier Coube, EPMA Technical Director, oc@epma.com</u>

EPMA European Hard Materials Group
Ultrasonic fatigue testing of hardmetals in the gigacycle regime Project Stage 1: Consortium Agreement
Issued 06 July 2009

The Project - Stage 1 as defined in Appendix 1
The Contractors – Institute of Chemical Technologies and Analytics, Faculty of Physics, Nanomaterials group TUW-UW, Materials Department CEIT, Materials Division NPL
The Members - **paid up corporate EPMA members*** funding the Project

UV = unanimous vote; MV = majority vote of 2/3 members or higher
Project Fee = full fee paid at start of Project Stage 1

Heads

1. The Members and Contractors agree to cooperate in order to complete the Project according to Annex 1.
2. All information generated under the Project will remain confidential to the Members during the Project and for one year after delivery of the final written report to Members, and may only be disclosed to third parties (e.g. for dissemination purpose in PM Congress) with UV.
3. The Contractors agree to not carry out a similar project on hardmetals with organisations other than the Members until the completion of the project (delivery of the final report). The aforementioned obligation shall not apply to other entities of TUW other than to its performing entity Institute of Chemical Technologies and Analytics and to other entities of UW other than its performing entity Faculty of Physics, Nanomaterials group
4. The Members agree to share equally the cost of the Project (EUR 27,500) through a Project Fee of maximum **EUR 6,875** per Member. The required minimum number of Members is **four** unless the Members agree to exceed the maximum Project Fee.
5. New paying members may be admitted during the Project by UV on payment of full Project Fee plus a reasonable premium (10%).
6. The terms of this agreement may be changed by UV.

Coordination will be by the EPMA, who will have responsibility for day to day liaison with the Contractors and keeping Members informed. The EPMA will operate under the same confidentiality agreement as Members and the EPMA President will be arbitrator for unresolved disputes.

Signatures: signed individually by all Members and Contractors

ORGANISATION:

NAME:

(Date signed)

***If you are not an EPMA member please contact Dr Olivier Coube, EPMA Technical Director, oc@epma.com**

Appendix 1: Work Packages in the Project:
Ultrasonic fatigue testing of hardmetals in the gigacycle regime Stage 1

1. WP 1 Selection and Manufacture of Test Specimens

Distribution of tasks:
- Selection of materials (2 grades): **all partners**
- Manufacture of test specimens: **Industrial Partners**
- Supply of material data: **Industrial Partners**
- Surface preparation: **Industrial Partners +TUW/UW**
- Measurement/supply of static properties, dynamic E: **Industrial Partners**

Cost:
- Contribution by industrial partners: cost not included here
Estimated duration: 1.5 Months

2. WP 2 Gigacycle Fatigue Testing

Distribution of tasks:
- Finish polishing, tuning of specimen shape, 15 x 2 gigacycle fatigue tests, preliminary fractography; dynamic Young's modulus (if necessary): **TUW+UW**

Estimated duration: 3.5 Months (**Available manpower:** Dipl.-Ing. Agnieszka Betzwar-Kotas >5 years experience in gigacycle fatigue testing)

3. WP 3 Measurement of Residual Stresses

Distribution of tasks:
- Measurement of residual stresses on 15x2 gigacycle fatigue test samples: **CEIT**

Estimated duration: 1 Month

4. WP 4 Measurements and Characterisations

Distribution of tasks:
- Fractographic investigations: **TUW/UW**, **NPL**
- Microstructural characterisation of damage during or after fatigue tests (by combining FIB, SEM, EBSD): **CEIT**
- Grain size and distribution by EBSD as well as FEGSEM images plus backup fractography (i.e. advice/consultation; imaging where difficulties arise): **NPL**

Estimated duration: 2.5 Months

5. WP 5 Project Management and Reporting

Distribution of tasks:
- Project Management: **EPMA**
- Final Report: **EPMA + WP 1-4 Leaders**

Estimated duration: WP 1-4 + 1 Month for Report

6. Costs:

TUW/UW: € 20,000; **CEIT**: € 2,500; **NPL**: € 2,500; **EPMA**: 10% Administrative cost (WP5 + Travels)

Total Cost: WP1-4 + 10% WP5 = € 27,500.-
Estimated total duration: ca. 8 Months