Ultrasonic Fatigue Testing of Hardmetals in the gigacycle regime "UFTH"
<u>Stage 2</u>

Presentation of the Project

Abstract
Based on results obtained in the project Stage 1, the gigacycle fatigue behaviour of hardmetals will be studied in ultrasonic fatigue resonance. The effect of surface related parameters such as roughness and residual stresses and that of the hardmetal grade, in particular of WC grain size and binder content, will be studied. In an optional work package, fracture mechanical studies will be done, in order to enable quantification of the effect of singular defects in the material.

Introduction
Gigacycle fatigue testing proved to be an effective tool to assess the mechanical behaviour of structural as well as functional materials. For tool steels it has been shown that while ingot metallurgy tool steels fail through cracking of carbides – many fairly large oriented carbides and carbide clusters being present in the microstructure – and the oriented microstructure results in anisotropic fatigue properties, in PM grades crack initiation is caused by the last few remaining non-metallic inclusions, for PM materials the stress levels being very significantly higher. For both types of materials, however, there is no "fatigue limit" as frequently claimed to exist for steels with bcc lattice, i.e. the S-N curves drop consistently up to 10E+10 cycles (and most probably also at still higher N). Surface compressive residual stresses, which are easily introduced, also inadvertently, by surface polishing, were found to increase the endurance level and shift crack initiation from the surface to the core region, which is desirable for practical applications but of course adversely affects the significance of fundamental fatigue studies.
For hardmetals, this testing method was regarded particularly attractive since there is no risk of adverse effects - such as premature failure - through uncontrolled bending loads which are very difficult to avoid in standard push-pull fatigue testing in which the specimens have to be clampled at both ends; furthermore, as a consequence of push pull loads the loaded volume is sufficiently high to render reliable information about the role of singular defects in the material; this is a very significant advantage compared to fatigue tests in bending.

Main Outcomes of the UFTH Stage 1 project:
In the UFTH project stage 1, the feasibility of this testing routine for hardmetals has been checked, and first material data were obtained. Furthermore:

- The adaptation of the ultrasonic resonance testing technique to hardmetals has been successfully performed, and the specimen preparation route has been defined. In particular the effect of annealing to remove surface residual stresses has been confirmed
- The first tests have shown that the S-N behaviour of hardmetals is similar to that of tool steels, not to ceramics; a "fatigue limit" has not been found up to 10E+10 cycles
- Knowledge about the appearance of crack initiation sites at extremely high N:
  Study of the fracture surfaces revealed predominantly surface/near-surface cracking; no clear „singular defects“ were observed, only occasionally large WC grains acted as initiation sites.

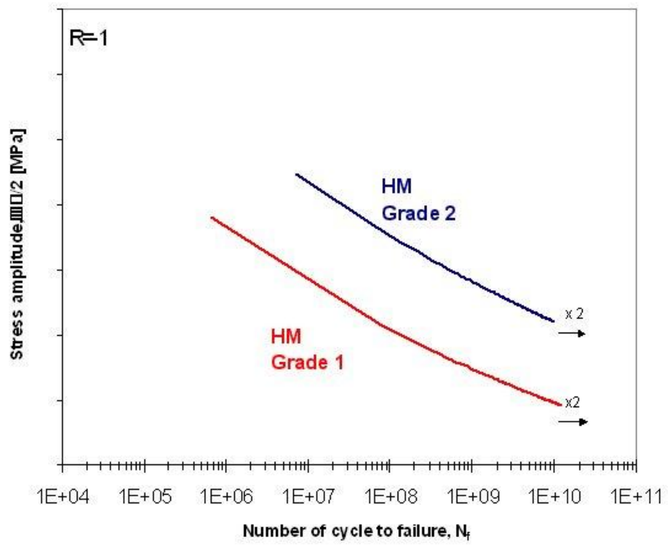

Fig.1: S-N graphs of two different hardmetal grades (UFTH Stage 1)

Fig.2: Hardmetal fatigue test bar for ultrasonic resonance testing (fixing by thread at one end)

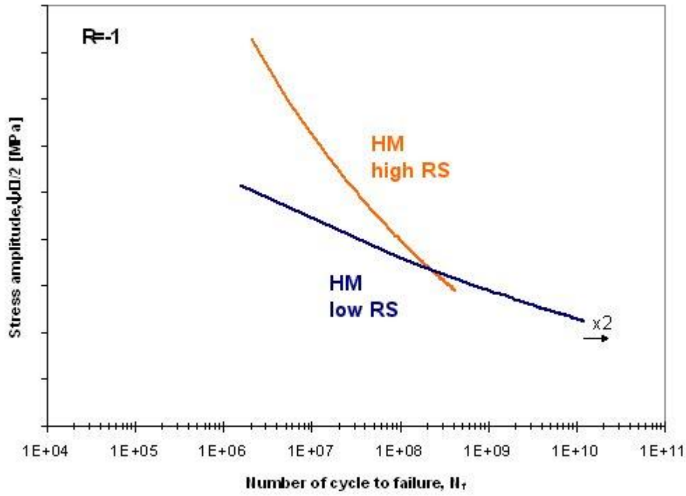

Fig.3: S-N graphs of HM grade 2 with different RS

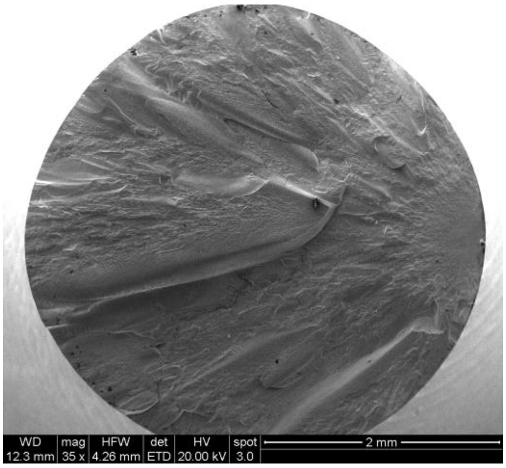

Fig.4: Fatigue fracture surface of hardmetal at about 10E+9 cycles (UFTH Stage 1)

Objectives of the Stage 2:

After the success of the UFTH Stage 1, the stakeholders have decided to continue the Ultrasonic Fatigue Testing of Hardmetals with the following objectives:

- Identification of the influence of internal parameters on fatigue behaviour of hardmetals (Microstructure-related effects “MRE”)
- *Optional: Identification of the influence of external parameters on fatigue behaviour of hardmetals (Surface-related effects “SRE”)*
- *Optional: Quantitative assessment of “defect” related effects through fracture mechanical studies (“defect”-related effects “DRE”)*

The UFTH Stage 2 project will be coordinated by the EPMA and scientifically led by the Vienna University of Technology-University of Vienna (TUW-UW) together with the Materials Department of the CEIT, San Sebastian, the Materials Science and Metall. Eng. Dept. of CIEFMA / UPC, Barcelona and the Materials Division of the National Physics Laboratory NPL, London.

Role of the Institute of Chemical Technologies and Analytics, TUW + Faculty of Physics, Nanomaterials group UW:

- Gigacycle fatigue tests (complete S-N graphs up to 10E+10 cycles) on HM specimens with varying surface state / with varying composition and microstructure
- Crack growth studies in the low and very low ΔK range; determination of ΔK_{th}
- Design of Kitagawa-Takahashi diagrams to enable quantitative assessment of the critical defect size in different HM grades.

Role of the Materials Department CEIT:

- Residual stress measurements (both in the binder and the WC phase)
    - Standard $\sin^2\psi$ technique
    - Glancing method to stressed materials (especially for coatings)
    - Neutron diffraction analyses
    - Non destructive testing with magnetic sensors for quality control at industrial scale
- Shot peening tests: new materials and methods. Characterization of the specimens surface before and after Shot peening: triboindenter+AFM, FEG-SEM
- Microtesting of cantilever beams with different sizes with and without FIB machined defects

Role of the Materials Division National Physics Laboratory NPL:

- Fractographic examination of selected fatigue testpieces.
- Characterisation of basic microstructure using high resolution FEGSEM and EBSD, including carbide grain size and distribution.
- Characterisation, using EBSD, of extent and magnitude of deformation gradients in carbide and binder phase in the surface of testpieces prepared by different techniques (grinding, etc).

Role of CIEFMA / UPC (Materials Science and Metall. Eng. Dept.):

- Damage evolution and analysis of crack/microstructure interaction during (if discerned) subcritical crack growth of fatigue-induced (surface) defects. Possible implementation of FIB techniques for in-depth analysis of surface-induced cracks.
- Fractographic examination of selected fatigue testpieces (complementary to NPL's activities)
- Fatigue mechanics analysis on the basis of fatigue endurance and FCG threshold: Influence of microstructure on fatigue sensitivity.

Role of the European Powder Metallurgy Association EPMA:
The European Powder Metallurgy Association will coordinate the project.

If you are interested in the project please sign and return to the EPMA the corresponding <u>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>