

EPMA European Hard Materials Group

Simulation of Fatigue Crack Growth in Hardmetal at a Mesoscopic Scale Project: "Simu-Crack Phase II"

Consortium Agreement

Issued 6 March 2013

The Project – "*Simu-Crack Phase II*" as defined in Annex 1

The Contractors –

- „RWTH Aachen für den Lehrstuhl für Werstoffanwendungen im Maschinenbau, Templergraben 55, 52062 Aachen, vertreten durch den Rektor oder die von ihm beauftragte Person": IWM RWTH Aachen
- Universitat Politècnica de Catalunya (UPC), C./ Jordi Girona 31, 08034 Barcelona, through CIEFMA (Centro de Integridad Estructural y Fiabilidad de Materiales, TECNIO member): CIEFMA UPC
- NPL Management Limited, Hampton Road, Teddington, Middlesex, TW11 0LW

The Coordinator – The European Powder Metallurgy Association EPMA

The Members - **paid up corporate EPMA members*** funding the Project

The Participants – The Contractors and the Members

UV = unanimous vote of Members and Contractors; MV = majority vote of 2/3 members or higher

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 5 years 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. NPL shall keep as confidential all information disclosed by the Participants of the "Simu-Crack Phase I" Consortium and the EPMA relating to the prior project entitled *Simulation of Fatigue Crack Growth in Hardmetal at a Mesoscopic Scale Project: "Simu-Crack Phase I"* whatsoever, without the permission of the Participants by UV. The Contractors and Members shall take all reasonable measures to keep confidential for a period of 5 years all information which is received from NPL under this Agreement and which is specified by NPL to be confidential information.

For **IWM RWTH Aachen**: Under the relevant provisions of the Universities Act NRW (Hochschulgesetz NRW), the contractor is obliged to publish in the usual scientific form the results of studies undertaken during performance of the project. The client gives his fundamental consent to such publication. In particular, the client will allow publication in connection with the taking of doctorates. The contractor will inform the client beforehand of any planned publication and will give him the opportunity of commenting upon it within a reasonable period, at latest ten (10) weeks after submission of the text intended for publication. A Member is entitled to refuse his consent to a publication if it is intended to publish company related data or, in connection with the granting of patent rights, if it is intended to publish any anticipatory information likely to constitute a bar to novelty. In such cases, the contracting parties will, without delay, seek to reach a special agreement governing the form and timing of rapid publication and taking due account of the legitimate interests of both parties.

For **CIEFMA UPC**: The Member is aware of the Contractor status as scientific research establishment, and, consequently, a generous attitude to publication shall be maintained. In order to ensure that no risk to potential patents is taken, however, no publication of any result from the Project shall be made without the Member written consent, which will not be unreasonably withheld. The Contractor shall supply the Member with the manuscript of the intended publication, and, within ten (10) weeks, the Member will respond with permission, or otherwise, to publish the manuscript either as is, or after suggested changes in content have been made. Failure of the Member to respond as specified will be considered as consent by default.

For **NPL**: The Member is aware of the Contractor status as a scientific research establishment, and, consequently, a generous attitude to publication shall be maintained. In order to ensure that no risk to potential patents is taken, however, no publication of any result from the Project shall be made without the Member written consent, which will not be unreasonably withheld. The Contractor shall supply the Member with the manuscript of the intended publication, and within (10) weeks, the Member will respond with permission, or otherwise, to publish the manuscript wither as is, or after suggested changes in content have been made. Failure of the Member to respond as specified will be considered as consent by default.

4. The Contractors agree to not carry out a “Simu-Crack Phase II” 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 NPL other than its performing entity Materials Division NPL, to other entities of UPC other than its performing entity CIEFMA research group and to other entities of RWTH other than its performing entity IWM.
5. The Members agree **to share equally the cost of the whole “Simu-Crack” Project** through a Project Fee of maximum **EUR 30,673.55** per Member according to the Payment Schedule detailed in 8. The required minimum number of Members is **four** unless the Members agree to exceed the maximum Project Fee.
6. Project Fee for Members of the “Simu-Crack Phase I” consortium will be of maximum **EUR 13,180.75** per Member, the deducted amount corresponding to Project Fees already covered during Stage I.
7. The Members also undertake to provide the Contractors with the necessary materials (powders, specimen etc...) for the project. If no agreement on in-kind contribution between the industrial partners can be found, the EPMA will coordinate this task “Work Package 0” and charge equally each Member to cover the cost plus an administrative fee of 10%.
8. **Payment Schedule:**
For the Work Package 0: Full payment within one month after invoice if necessary.
For “Simu-Crack Phase II” project:
 - **50% at the start,**
 - **50% after completion** of the Simu-Crack Phase II project and delivery of the final report.
9. New paying members may be admitted during the Project by UV on payment of an additional reasonable premium (10%). The premium will be used to decrease the Project Fee for the Consortium Members.
10. Except for the deliverables of the Annex 1, each Participant will retain the Intellectual Property for any other outcomes of the project.
11. Warranty. The contractor's warranty extends solely to the use of due scientific diligence and to compliance with accepted engineering practice. The contractor does not guarantee that the desired objectives of the research and development project will be achieved.
12. NPL accepts no responsibility for the use made of any information, materials or equipment arising from the performance of the work, whether by the Member or by any third party who has obtained any of the said information, materials or equipment directly or indirectly from the Member, except to the extent that NPL can be shown to have been negligent in providing such information, materials or equipment.
13. Liability. The contractor is liable solely for wilful actions and gross negligence. Liability for proven direct damage is limited to the amount of the contractual sum received by Contractor under this Agreement. For the avoidance of doubt the Contractor shall not be liable for any indirect or consequential loss. .
14. Coordination will be by the EPMA, who will have responsibility for invoicing, 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 by the Members. Should the Parties fail to do so, then such dispute shall be subject to the exclusive jurisdiction of the English Courts. The laws of England and Wales govern all matters arising out of or relating to this agreement, and all transactions contemplated hereby, including, without limitation, its validity, interpretation, construction, performance and enforcement.
15. Except for the terms 5, 7, 8, 11, 13, 13, 14 all the terms of this agreement may be changed by UV.

Coordination will be by the EPMA, who will have responsibility for invoicing, 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:

VAT Number:

NAME:

(Date signed)

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

Annex 1

EPMA European Hard Materials Group

Simulation of Fatigue Crack Growth in Hardmetal at a Mesoscopic Scale: “SIMUCRACK Phase II”

Project Description

Objectives

The proposed stage II of the project follows two objectives:

1. **To demonstrate that fatigue crack propagation through the microstructure of hardmetal can be numerically simulated with a numerical model using the finite element method.**
2. **To develop models able to do a qualitative prediction of crack path (on the basis of experimentally observed crack-microstructure interaction) under cyclic loading.**

Work packages

WP1 Improvement of the numerical model

(IWM/UPC)

- Improvement of the damage model, including indirect consideration of stress-induced FCC to HCP phase transformation and/or fcc twinning of metallic binder. This will be attempted by using a field subroutine coupling stress state of crack tip to the elasto-plastic material properties. Implementation will require measurement of elasto-plastic properties of a model-like HCP alloy, beyond those already measured for the model-like fcc one, and estimation of stress required to trigger the referred FCC to HCP phase transformation and/or FCC twinning. Additionally, crystallographic-like crack paths (as experimentally observed) will be imposed (artificial deviation) such to match real crack growth paths. (IWM)
- EBSD study and spherical nanoindentation assessment of stress required to induce FCC to HCP transformation and/or FCC twinning (both as a function of grain

orientation) on model-like binder alloy produced in Stage I
(UPC)

Deliverables WP1:

- i. Input for Abaqus FCC to HCP phase transformation and/or FCC twinning subroutine

WP2 Production of precracked specimens (UPC, IWM)

- Production of plain bending specimens (industry)
- 1 hardmetal grade with a coarse-grained and mid-value binder content (similar to E10 grade used in other Club Projects) (industry)
- Production of small “surface cracks” using FIB (sharp FIB-notching) (UPC)
- EBSD characterization of binder grains in region surrounding notch (UPC)
- Crack propagation due to cyclic loading in a SEM (in situ SEM) (IWM)
- Experimental determination of crack growth rate in the meso-scale (IWM)
- Evaluation of correlation between crack path and binder orientation (UPC)

Deliverables WP2:

- i. graphic documentation of stable cyclic crack propagation
- ii. crack growth rate as function of ΔK
- iii. microstructure-crack interaction on the basis of binder orientation
- iv. precracked specimens for WP4

WP3 CAD-file of a “thick” 2D-microstructure (UPC)

- FIB-CT of the microstructure for generation of discrete “thick” 2D meshes to be used in WP5
- FIB-specimen taken from an undamaged part of the specimens produced in WP2

Deliverables WP3: CAD-files with coordinates of carbides usable as input file for FE Models

WP4 Experimental determination of 3D-crack path (UPC)

- FIB-CT of the cracked specimens produced in WP2
- Qualitative description of crack path through the microstructure

Deliverables WP4: crack growth pattern depending on the microstructure

WP5 FE models of crack propagation in “thick” 2D meshes (IWM)

- generation of FE-meshes based on the CAD-files obtained from WP3
- Qualitative prediction of the “thick” 2D crack path through the microstructure
- Prediction of crack growth rate

Deliverables WP5: diagram da/dN and micromechanical understanding of FCG behaviour

WP6 Metrology of the structure of Co binder alloys (NPL)

An understanding is needed of the existing structure of the Co binder phase and the proportion of the HCP and FCC phases present before and after fatigue. The spatial variation of the HCP/FCC ratio is not known and assessment of the ratio is complicated by the probability that preparation techniques, especially FIB, can alter the observed HCP/FCC ratio.

- The effect of surface preparation techniques on the HCP/FCC ratio will be investigated in WC-Co alloys and in model Co-W-C alloys
- The local variation of the HCP/FCC ratio and local microstructure will be analysed in the above by EBSD after understanding how to observe the true structure

Deliverable WP6: Written report on specimen preparation methods and uniformity of the Co structure.

WP7 Project management and reporting (EPMA+IWM)

The project management will be supported by EPMA. Two or three meetings with all contractors would be held, a kick-off meeting if necessary, one approximately half way through to report on progress and one wind-up meeting at project completion. The final report will be written by IWM and EPMA.

Deliverables WP7: Quarter reports and 1 final report

Work package time planning

Duration of the project: 12 months

Work Package	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
WP1: improvement of the model (IWM) Input data associated with stress-induced FCC to HCP phase transformation and/or FCC twinning at grain-scale (UPC)	█	█	█	█	█	█						
WP2: production of precracked specimens												
plain specimens (industry)	█	█										
FIB-notch+EBSD (UPC)			█	█	█	█						
Crack propagation in SEM (IWM)						█	█					
WP3: CAD-file of 2D/microstructures (UPC)			█	█	█	█						
WP4: Exp. det. of 3D-crack path (UPC)						█	█	█				
WP5: FE-models of crack growth (IWM)					█	█	█	█	█	█	█	█
WP6: Metrology of the structure of Co binder alloys (NPL)	█	█	█	█	█	█	█	█	█			
WP7: Project Management & Report	█	█	█	█	█	█	█	█	█	█	█	█

Costs for phase II:

RWTH (IWM)	personnel:	0.2 full engineer for 12 months:	€ 12,740
		0.2 technician for 4 months:	€ 2,670
		0.5 student for 12 months:	€ 2,600
	consumables:		€ 1,500
	travel:		€ 1,500
	overheads (41%):		€ 8,615
		total funding (cost - 5% for NPL):	€ 28,144
UPC	personnel:	0.1 professor for 3 months:	€ 1,850
		0.1 technician for 4 months:	€ 1,575
		0.5 Master student for 9 months:	€ 7,810
	consumables:		€ 3,250
	travel:		€ 1,200
	overheads (16,7%):		€ 2,620
	total funding (cost - 10% for NPL):	€ 16,475	
NPL	total funding:	€ 3,311	
EPMA	administrative costs (10%)	€ 4,793	
Total costs of project phase II:			<u>€ 52,723</u>

All costs exclusive VAT if applicable