

EPMA European Hard Materials Group

Simulation of Fatigue Crack Growth in Hardmetal at a Mesoscopic Scale Project: "SIMU-CRACK Phase III"

Consortium Agreement

Issued January 2016

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

The Contractors –

- „RWTH Aachen für den Lehrstuhl für Werkstoffanwendungen 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 54,566.22** per Member according to the Payment Schedule detailed in 10. The required minimum number of Members is **three** 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 37,073.42** per Member, the deducted amount corresponding to Project Fees already covered during Phase I.
7. Project Fee for Members of the “Simu-Crack Phase I” and “Simu-Crack Phase II” consortium will be of maximum **EUR 23,892.67** per Member, the deducted amount corresponding to Project Fees already covered during Phase I and Phase II.
8. **VAT**: VAT will be added to the Project Fee as appropriate but may be reclaimed according to local arrangements (e.g. “Reverse Charge” mechanism). All VAT numbers are to be provided to the EPMA.
9. 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 equally charge each Member to cover the cost plus an administrative fee of 10%.
10. **Payment Schedule:**
For the Work Package 0: Full payment within one month after invoice if necessary.
For “Simu-Crack Phase III” project:
 - **50% at the start,**
 - **50% after completion** of the Simu-Crack Phase III project and delivery of the final report.
11. New paying members may be admitted during the Project by UV on payment of an additional reasonable premium (10%) regardless Heads 5, 6 and 7. The premium will be used to decrease the Project Fee for the Consortium Members.

12. Except for the deliverables of the Annex 1, each Participant will retain the Intellectual Property for any other outcomes of the project.
13. 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.
14. 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.
15. 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. .
16. 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.
17. Except for the terms 5, 9, 10, 13, 15, 15, 16 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 III”

Project Description

Objectives

The proposed stage III of the project follows two objectives:

- Assessment of the influence of carbon content (as additional variable, besides binder content and carbide grain size) on the fatigue crack growth (FCG) of WC-Co cemented carbides.
- Numerical validation of the experimentally observed FCG process for various hardmetal grades with the already developed modelling approach.

The proposed objectives will be achieved through four workpackages (WP), three being technical and one being administrative. With this third phase, the methodology generated will be transferred to the project partners and the SimuCrack project will be finalized.

WP1. Production and mechanical characterization of hardmetal grades with different carbon content (Ceratzit + UPC)

Aiming to expand and develop the simulation efforts/capabilities developed in previous stages, an experimental workpackage is proposed whose main objective is to document and gather information on carbon content effects on the fatigue crack growth behavior of WC-Co cemented carbides. In doing so, three different grades will be studied with alike binder content and carbide grain size, but different carbon content: high, medium and low, all of them within the two-phase (WC plus Co) field.

The study will include not only assessment of FCG kinetics and corresponding fractographic analysis, but also detailed characterization of microstructure, evaluation of fracture toughness and investigation of fracture/fatigue micromechanisms involved.

WP1.1. Production of the hardmetal grades (Ceratzit)

Specimens to be tested will include 3 WC-Co grades, on the basis of carbon content as main experimental variable. Reference grade will be E10, as provided by CERATIZIT. Grades will be produced with the composition of E10, but changing relative carbon content: high, medium and low.

Deliverables: E10 samples with different carbon content for FCG characterization.

WP1.2. Testing and mechanical characterization (UPC)

The mechanical characterization will involve an important part of the project. Within this context, the predefined three sets of specimens will be subjected to the following analyses/tests:

- Fracture toughness (SENB specimens [45x10x5 mm], precracking, testing, 5 samples per set will be required).
- Fatigue Crack Growth behavior (SENB specimens [45x10x5 mm], precracking, two load ratios, experiments to evaluate the crack growth behavior, evaluation of fatigue crack growth thresholds, 10 samples per set will be required).

Deliverables:

- i. Data for characterizing the overall fracture and FCG behavior for the hardmetal grades.
- ii. Precracked samples for experimental set out to be modeled (input data and validation).

WP2. Crack-microstructure interaction and fractographic inspection (NPL)

Crack-microstructure interaction under stable crack growth regime will be assessed for at least one sample from each of the three grades. Main actions will include: (1) quantification of the crack extension paths (interfaces, binder, carbide), and (2) comparison of 2D and 3D measurements, the latter documented both by means of FIB and by polishing through at least one sample to compare plane stress at the surface with plane strain (or nearer this condition) internally. Extensive and detailed fractographic characterization on broken surfaces will also be carried out.

Deliverables: Description of crack-microstructure interaction in each grade and detailed characterization of the fracture/fatigue process.

WP3. Assessment of the FCG process for the hardmetal grades by means of simulation (IWM)

The already developed numerical methodology will be further tested and verified with respect to the new specimens. As an additional input, this time the simulations will also take into account the effect of thermally induced residual stresses. In this regard, models with and without the residual stresses will be prepared. By comparing the simulation results from these two different configurations, the real influence of the residual stress over the FCG mechanism will be determined.

In order to simulate the residual stresses, a basic thermal contraction step will be introduced to the models before the mechanical loading step. The thermal expansion coefficients for the WC and Co phases will be derived from literature.

An experimental program for determining the other mechanical properties of the individual phases will be also not conducted. Instead, the parameters for the new binders will be estimated from the previously produced representative binder alloy (SimuCrack Phase II), based on the carbon content.

The precracked samples generated in WP1.2 will be used as basis for the numerical models. The microstructural models will be once again prepared based on SEM images and will be simulated similar to the experimental conditions. The estimated binder parameters will be as

well validated during this stage and will be modified in order to capture the correct crack growth patterns.

Finally, the simulation results will be compared and validated with respect to the overall experimental findings in WP1 and WP2.

Deliverables: Simulation results for the 3 hardmetal grades

WP4. Support for the implementation of the developed methodology (IWM)

The damage approach implemented to Abaqus software consists of various technical stages such as, microstructural model generation (based on real or artificial structures), definition of material parameters to the damage subroutine and implementation of the boundary and loading conditions for the cyclic loads. Currently, such an approach can be practically conducted in IWM, but successful implementation at industrial partners' sites is unclear.

Considering above scenario, the aim of this workpackage is to support the industrial partners for getting more familiar with the model generation and implementation of the subroutine in Abaqus. In this regard, a practical guideline will be prepared by the end of the project and if requested, further demo visits to the partners will be done.

Deliverables: Practical guideline for implementing the damage model to Abaqus.

WP5. Project management and reporting (EPMA/IWM/UPC/NPL)

Once again, the project management will be supported by EPMA. Three technical meetings (including a kick-off one) with all contractors would be held. The technical presentations will be once again provided as the interim reports. A final report, documenting the overall activities and general results, will be provided to the consortium members.

Deliverables: Interim report in the form of technical presentations and one final project report documenting the overall activities and general results.

Work package time planning

Duration of the project: **15 months**

#	1 (KM)	2	3	4	5	6	7	8 (IM)	9	10	11	12	13	14	15 (FM)
WP1															
WP1.1															
WP1.2															
WP2															
WP3															
WP4															
WP5															

KM: Kick-off meeting, **IM:** Interim Meeting, **FM:** Final Meeting

Costs for Phase III:

RWTH (IWM)	personnel:	0.3 full engineer for 11 months:	16,170 €
		0.3 technician for 1 months:	1,190 €
	travel:		5,000 €
	overheads (41%):		9,167 €
	total funding :		31,527 €
UPC	personnel:	0.1 professor for 2 months:	1,240 €
		0.1 technician for 3 months:	800 €
		0.5 master student for 9 months:	8,100 €
	consumables:		2,880 €
	travel:		1,200 €
	overheads (17.7%):		2,515 €
total funding :		16,735 €	
NPL	personnel:	0.1 senior scientist for 4 months:	9,100 €
		0.1 research scientist for 4 months:	5,900
	travel:		1,900 €
	total funding :		16,900 €
EPMA	administrative costs (10%)		6,516 €
Total costs of project phase III:			71,678 €

All costs exclusive VAT if applicable