Resistivity of Hardmetals – Part Two (RoH2)

EPMA European Hard Materials Group EHMG
Collaborative Research Proposal – November 2015

Proposal Introduction

A previous EHMG project (**RoH**) was conducted to acquire electrical resistivity and thermal property data for a wide range of hardmetals between room temperature and 800 ºC, in order to:

- assess potential for new quality control techniques with the added advantage of characterising non-magnetic materials and with application to a wide range of sample sizes
- provide data for modelling performance applications where higher temperatures than ambient are experienced

Electrical and thermal conductivity measurements for hardmetals in project RoH [1] demonstrated significant potential as new quality control techniques for hardmetals with the added advantage of being able to characterise non-magnetic materials. Thermal property data on fully characterised materials is required by industry to optimise the performance of hardmetal components in many applications where heat is generated through contact mechanics. Such data will also contribute for modelling performance applications where higher temperatures than ambient are experienced.

In **RoH** a systematic study of the effects of microstructural variables yielded understanding that could be directly applicable to more accurate modelling of the thermomechanical behaviour of hardmetal components. **RoH** was assisted by the development of a model for thermal conductivity from the known properties of the individual constituents using mean field approaches (MFA). By assuming that the thermal properties were not affected by the fabrication processes, the effect of phase size and shape (and if necessary, orientation) and interfacial properties on the overall behaviour of the material were modelled to give the theoretical maximum possible conductivities. Validation of the model with experimental measurements enabled a wider range of structures/compositions to be examined.

This current project (**RoH2**) proposes to follow on from **RoH** by addressing the following five objectives:

Objective 1 – Contiguity

It is clear from the modelling studies in project **RoH** that interface conduction has a significant effect on properties. Therefore contiguity, i.e. the average fraction of the surface of individual WC grains in WC/Co hardmetals is an important parameter to measure. It is proposed that the contiguity, measured on 2D images, is assessed in the **RoH** materials. This will require some preliminary research on the optimum method (SEM or EBSD) for imaging the microstructures together with an interlaboratory measurement exercise to quantify uncertainty.

Objective 2 – Co alloy research for input data to modelling studies

The CEIT models were clearly sensitive to the thermal properties of the binder phase and although NPL contributed measurements of electrical properties of pure Co and two Co-W-C

alloys no thermal properties were assessed. It is proposed that 3 new Co-W-C alloys be manufactured at low, medium and high W levels with around 0.1wt% C. Their thermal and electrical properties would be measured and this will allow CEIT to reassess their model predictions as well as providing further insight on the thermal performance of WC based hardmetals.

Objective 3 – Binderless pure carbides

Both the modelling and experimental contributions to **RoH** indicated that the electrical and thermal properties of the two phase WC-Co structure were sensitive to interface conductance of the WC phase. It is proposed to examine one aspect of this dependence by measuring the electrical and thermal properties of pure WC manufactured with at least three different grain sizes. These would be sourced through industrial participants or academic contacts. CEIT and NPL would measure the temperature dependence of thermal diffusivity and electrical conductivity.

Objective 4 – Modelling – input data sensitivity and model upgrade

The model developed within **RoH** for the thermal conductivity and electrical resistivity of hardmetals has proved valuable in gaining an understanding of the effect of the microstructure and interfacial properties on hardmetal behaviour. However, its potential has not been fully exploited during the project and project partners expressed interest in a user-friendly version in Matlab to be transferred to the industry. It is proposed to produce a user-friendly version in Matlab which could be used as a tool to design hardmetals with tailored thermal conductivity and be able to predict electrical resistivity. Input parameters and capabilities need to be defined and a sensitivity analysis to input data will be performed. The model will also have a tool to determine interfacial properties by comparing actual and predicted thermal conductivity (or electrical resistivity) as shown in the previous **RoH** project.

References

1. B. Roebuck, H.G. Jones, K.P. Mingard, M.R.Elizalde Gonzalez and J.M. SanChez Moreno. Electrical Resistivity and Thermal Properties of Hardmetals EPMA-EHMG, NPL Report MAT (RES) 238, November 2014.

Proposed Project Timetable

It is anticipated that practical work in the project would commence in late 2015 and be completed within 18 months. An outline management chart is included after the reference section. The project would kick off with a teleconference to confirm material supply and decide on modelling input/outputs. Two discussion meetings with participants would be held, one approximately half way through to report on progress and one wind-up meeting at project completion. Work at partner organisations to prepare materials should start as soon as the project has sufficient members to meet the financial requirements.

Proposed Project Management

The EPMA will oversee the project and ensure that NPL and partners meet their commitments. The EPMA will use various methods (web, etc) to ensure satisfactory dissemination of the project outcomes.

Proposed Project Costs

The cost to each participating industrial partner would be dependent on numbers taking part but **50% of the research at NPL will be co-funded by other NPL projects on the understanding that some of the metrology aspects are directly publishable after consultation with partners, thus reducing their total to €33k.** The following costs take this reduction into account. A working target, including some final testpiece shaping and possible Co alloy production, would be:

- **€33k** for the Contiguity exercise and further thermal and electrical resistivity studies on binders and carbides at NPL **and €2k** for complementary thermal diffusivity (about 4 samples) and contiguity measurements (about six samples) at CEIT.
- **€14.5k** for the development of the Matlab model by CEIT.
- **€6.3k** for administrative costs of the EPMA

So the overall cost of the project to the project partners would be <u>€55.8k</u> (excluding VAT if applicable*).

Costs would be **<u>shared equally</u>** between the industrial participants.

Payment would be made in several instalments. For example three partners would be required to contribute in two instalments a total of ca. €18.6k each.

** Non UK participants do not pay VAT provided they give their VAT number to the EPMA. UK participants have to pay VAT regardless and then reclaim it.*

The industrial participants will be expected to contribute to the Selection and Manufacture of Test Specimens (WP0).

<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
Resistivity of Hardmetals 2 (RoH2)
Consortium Agreement
Issued November 2015

The Project - As defined in Annex 1
The Contractors – Materials Division NPL, Materials Department CEIT
The Members - **paid up corporate EPMA members*** funding the Project
The Participants – The Contractors and the Members

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 data generated under the Project will remain confidential to the Members during the Project and for THREE 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 of the Members.

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).

4. The Members agree to share equally the cost of the Project (EUR 55800), excluding the Work Package 0 (Selection and Manufacture of Test Specimens). The required minimum number of Members is **three** unless the signed up members agree to exceed a specified maximum Project Fee.

5. 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.

6. The Members also undertake to provide the Contractors with the necessary test specimens and their appropriate surface preparations (Work Package 0 “WP 0”). If no agreement on in-kind contribution between the industrial partners can be found, the EPMA will coordinate the WP 0 and charge equally each Member to cover the cost of WP0 plus an administrative fee of 10%.

7. Payment of fees must be made promptly on receipt of invoice by TT to the nominated EPMA account.

    - 50% at the start of the project
    - 50% after completion of the project stage and delivery of the Final report.

8. New paying members may be admitted during the Project by UV on payment of full Project Fee plus a reasonable premium to include contribution to the prior RoH project (amount to be decided by UV). Participation and access to the Project’s results and

deliverables is unlikely to be agreed after completion of the project though if required an agreement by UV would be necessary.

9. Each Participant will retain the Intellectual Property for any other outcomes of the project. The Intellectual Property from the Resistivity of Hardmetals reports shall be owned by the Members.

10. The contractor's warranty extends solely to the use of due scientific diligence and to compliance with accepted engineering practice. The contractors do not guarantee that the desired objectives of the research and development project will be achieved.

11. Liability. Each Party is liable solely for wilful actions and gross negligence. Liability for proven damage is limited to the amount of the contractual sum.

12. 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.

13. Except for the terms 4, 7, 8, 10, 11, 12 and 13 all the terms of this agreement may be changed by UV of the Members.

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: Work Packages in the Project:
Resistivity of Hardmetals 2 (RoH2)

1. WP 0 Selection and Manufacture of Test Specimens

Programme: Industrial partners to agree suitability for the project of a range of hardmetals with varying Co content (5-30 wt%), WC grain size (0.5-5 μm) and carbon content (across the two phase WC-Co region). Materials from the **RoH** and Modulus projects are probably suitable, but others could be supplied by negotiation. Partners will assist an acquisition of new Co(W,C) and binderless WC materials.

Distribution of tasks:

- Selection of materials : **all partners.**
- Supply of material data: **Industrial Partners**
- Surface preparation: industrial partners to supply specimens ground to shape and blanks for common grinding route at NPL. **Industrial Partners**
- Measurement/supply of static properties: **Industrial Partners**
- Pre-test (if necessary) and final test samples shaping: **NPL**

Cost:
- Contribution by Members (industrial partners): cost not included here. If no agreement on in-kind contribution between the industrial partners can be found, the EPMA will coordinate the WP 0 and charge equally each Member to cover the cost of WP0 plus an administrative fee of 10%.

Estimated duration: Months1-6. **Deliverables**: Test samples (see presentation of the project)

2. WP 1 Contiguity

Programme: NPL will examine the metrology associated with acquisition of contiguity data from electron optical structure images and report on the variation of contiguity with Co content and WC grain size in the **RoH** materials. An interlaboratory exercise will be conducted between all partners on selected images.

Estimated duration: Months 1-12. **Deliverable**: NPL Report on the metrology of contiguity measurements and data on at least 20 representative hardmetals.

3. WP 2 Co alloy research for input data to modelling studies

Programme: Three Co(W,C) alloys with low, medium and high W content and around 0.1 wt%C will be acquired for electrical and thermal studies. NPL will measure the temperature dependence of electrical properties and NPL and CEIT will share the task of measuring the thermal properties. CEIT will reassess their model predictions.

Estimated duration: Months 1-15. **Deliverables:** NPL/CEIT report on the temperature dependence of the electrical and thermal properties of three representative Co(W,C) alloys.

4. WP 3 Binderless pure carbides

Programme: NPL, CEIT and partners will decide on one or more manufacturing routes for a set of binderless WC materials with at least three different grain sizes. Once acquired NPL and CEIT will measure their electrical and thermal properties as in WP3.

Estimated duration: Months 6-18. **Deliverables:** Report on temperature dependence of the electrical and thermal properties of three binderless WC materials.

5. WP 4 Modelling – Input data sensitivity and model upgrade

Programme: CEIT will develop a user friendly option in Matlab for their thermal model supported by a sensitivity analysis of variations in input data.

Estimated duration: Months 1-16. **Deliverables:** CEIT user friendly thermal model.

6. WP 5 Project Management and Reporting

Programme: The EPMA will oversee the project and ensure that NPL and CEIT meet their commitments. The EPMA will use various methods (web, etc) to ensure satisfactory dissemination of the project outcomes.

Distribution of tasks:

- Project Management: **EPMA**
- Final Report: **EPMA , NPL, CEIT**

Estimated duration: WP 0-5 + 1 Month for Report

7. Costs:

NPL: €33k, (WP1-3); **CEIT**: €16.5k (WP 2-4); **EPMA**: Admin cost (WP 0 and 5): €6.3k
Total Cost: WP1-5 = €55.8k (excluding VAT if applicable and WP 0)
Estimated total duration: ca. 18 Months

8. Proposed Project Timetable:

It is anticipated that practical work in the project would commence in late 2015 or beginning 2016 with a teleconference and be completed within 18 months. Two discussion meetings with contractors will be held, one approximately half way through to report on progress and one wind-up meeting at project completion. Work at partner organisations to prepare materials should start as soon as the project has sufficient members to meet the financial requirements.

	Month																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
WP0																		
Kick-off discussion/Agreement of Programme																		
Manufacture of samples		See WPs below																
WP1 Contiguity																		
Acquisiiton of maps/images on range of samples							NPL											
Interlab study										All								
Analysis and report of interlab													NPL					
WP2 Co alloy research																		
Production of Co(W,C) alloys							Aachen?											
Electrical property measurement										NPL								
Thermal Property measurement&models														NPL/CEIT				
Report																NPL/CEIT		
WP3 Binderless Carbides																		
Obtain 3 grain sizes										All								
Electrical property measurement													NPL					
Thermal Property measurement&models																	NPL/CEIT	
Report																		NPL/CEIT
WP4 Modelling																		
Matlab tool											CEIT							
Sensltivity analysis													CEIT					
Report																	CEIT	
WP5																		
Project meetings																		
Final Report																		NPL/CEIT