

Publishable final activity report

CONTRACT N° NMP3 – CT – 2005 - 500140

ACRONYM: CMA

**TITLE: EUROPEAN NETWORK OF EXCELLENCE
COMPLEX METALLIC ALLOYS**

**PROJECT CO-ORDINATOR: Centre National de la Recherche Scientifique (CNRS)
Délégation Régionale pour le Centre-Est, France**

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20 - TEMAS AG, Technology and Management Services	CH	TEMAS

REPORTING PERIOD FROM: 01/07/2005 to 30/06/2010

PROJECT START DATE: 01/07/2005

DURATION: 60 months

Date of issue of this report: August 14, 2010.



CMA
complex metallic alloys

Project funded by the European Community

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1 Publishable Executive Summary

Introduction:

The CMA (Complex Metallic Alloys) network of excellence (CMA-NoE hereafter) was designed to contribute to a strengthening of the competitiveness of metallic materials for the benefit of European industries. It was due to develop within five years into a *European Integrated Centre for the Development of New Metallic Alloys and Compounds* (called C-MAC nowadays). This Centre was to unite an appropriate number of specialised European laboratories to form an integrated body dedicated to the intelligent search for new metallic materials and their development towards technological applicability. Collaborating on a first challenging topic, *Complex Metallic Alloys*, these laboratories were going to build up C-MAC, put it into practice and demonstrate that it is capable to embark upon the research and development of materials that could not be dealt with before.

As a matter of facts, CMA-NoE has united 26 high-reputation institutes in 20 European institutions, representing a person.year critical mass of more than 330 person.years and 60 PhD students in 12 countries in Europe. CMA-NoE has received a total funding of 7.3 M€ from the EC. The total human resources allocated to the project by the partners is estimated well above 50 M€ in five years. CMA-NoE has carried out a number of integration and dissemination tools and has achieved a large number of breakthroughs in the field of metallic alloys. These different facets of the joint program of activity are summarized successively in the following.

Joint Program of Integration: Architecture of CMA-NoE in VILs and VIUs

CMA-NoE established its internal research structure during the Year 1 (Y1) of the project. This structure was based on six Virtual Integrated Laboratories (VILs) in which more than 330 permanent scientists and 60 PhD students were enlisted. Virtual Integrated Units (VIUs), closely involved in integration and dissemination activities (missions, innovation and knowledge spreading, gender mainstreaming, knowledge management and higher education lecturing and publishing), have reinforced the action of the VILs.

The network activity was focused on five specific classes of complex metallic alloys, which were carefully selected for their potential to establish broader knowledge of the crystallographic structures, defects and properties of complex compounds made of metals with a view to applications based either on magnetocaloric properties, thermoelectricity, hydrogen storage, catalysis or reinforcement of light mechanical components. Used as a case study to test the functioning of CMA-NoE, the basic study of one such family, namely $\beta\text{-Al}_3\text{Mg}_2$ was nearly completed during Y1 and a significant number of papers submitted to specialised journals.

Integration was essentially addressed during Y1 to Y5 by means of joint meetings, cross-linking countries as well as disciplines. Considerable effort was focused on personnel exchange.

Joint Program of Integration: The Mission service

The Mission Service VIU MS (director: E. d'Hoedt, CRPHT, Luxemburg) was functioning during the whole duration of the network to the benefit of all partners (with two exceptions however, MPG in Germany and TEMAS, a private company under Swiss fiscal law). The VIU MS was in charge of reimbursing all individuals travelling on a CMA mission. Reimbursement was achieved on an identical basis for all missioners, whatever their citizenship and institution of attachment, and proved to be very efficient and cost-effective after just very few months, which in the whole was a serious step towards integration. Reimbursement rates were copied from the ones applying for European civil servants.

Joint Program of Integration: Higher education

A strong program for higher education was run by CMA-NoE during its five years of existence. This program consisted on the one hand in the so-called Euroschool and on the other hand, the EuroPhD scheme. The Euroschool was organised at Hotel Mons, Ljubljana by Jožef Stefan Institute (director of the Euroschool: Prof. J. Dolinsek, JSI, Ljubljana) and has consisted in five sessions held every year during the last week of May. Five different topics were addressed (see below), with an average attendance of about 150 participants every year. Lecturers came from CMA-NoE partners, but also from companion institutions in the US, Japan, Korea, China and India. The sessions, except in Y5 due to shortage of funds, were all associated with a book published and marketed by World Scientific. As from Y3, the University of Ljubljana awarded ECTS credits to junior participants in the Euroschool (under certain conditions).

The EuroPhD program has allowed a dozen of students to perform their PhD on CMAs under the joint supervision of (at least) two supervisors in two different partner institutions located in two different countries in Europe. Long-term research programs could thus be undertaken within the VILs of CMA-NoE. Most often, the PhD has benefited from another financial resource in addition to the EC funding.

Joint Program of Integration: Gender mainstreaming

This program was very successful, thanks on the one hand to the persisting and very careful efforts of the VIU GM director (Prof. A. Czyrska-Filemonowicz, AGH-UST, Krakow) and staff, and on the other hand, to the support by network members. It resulted in a number of actions, of which we shall mention the actual parity decided, and obtained, in selecting invited speakers at international meetings or colloquia organised by CMA-NoE.

Joint Program of Integration: The successor structure of CMA-NoE

The transformation of the network into a long-lasting structure called initially IDEA has been studied from the very beginning of the network. At the turn of Y1-Y2, the decision was made to restrict the number of partners involved in the study of IDEA to six (partners n°1 to 4, 8 & 13) in order to experiment first the legal structure on a very pragmatic basis and open it to the other CMA partners at a later stage. Our study of the advantages and drawbacks brought in by the various legal possibilities converged to a consortium very similar to the present one, bound by a formal agreement that will allow it raise its own funding. More formal legal structures, like an EEIG, were found inappropriate, especially by partner 1 (CNRS) who is not allowed to enter such a legal body.

The project then evolved, especially thanks to partner 20 (TEMAS), who joined the CMA-NoE in Y2. It was found after Y2 that a mixed legal structure, joining on the one hand a simple consortium of the same kind as CMA-NoE, with all partners on board (and especially CNRS) and on the other hand a non-profit association under Belgian law, with a smaller number of partners (exclusive of CNRS) could achieve the goal. This body, named C-MAC, was progressively constructed until it entered into force during Y5. It is now active and has already taken over in parallel to CMA-NoE. Its governing body has already met twice in Y4-Y5. A business plan was presented at the last review meeting of CMA. Its start event took place at the C-MAC 1 conference organised in October 2009 to finalise the joint program of research of CMA-NoE and launch the activity of C-MAC.

Joint Program of Integration: The Senior Advisory Council

The Senior Advisory Council (SAC) started partial operation in the first year of CMA, but had to stop after the withdrawal of its president in 2006. It was reshaped in Y3 and entered into action in May 2008. Four international experts of different citizenships, two from European industry and two from university, have constituted it (Chair: W. Huppmann, members: T. Janssen, J.M. Tarascon and T. Hack). Its role was to evaluate the targets and achievements of the network, while providing advises on all topics of relevance. Due to its multinational, multidisciplinary constitution, the SAC played a great role in integrating the various forces active in the network along a same trend of objectives.

Joint Program of Dissemination: Innovation transfer

Finally, after deep re-organisation in the mid of Y1, the VIU IT, involved in Innovation Transfer, came to a steady state, functioning thanks to the new partner TEMAS joining CMA-NoE in the course of Y2 (Director of VIU IT: K. Hoehener, TEMAS, Arbon). The VIU IT played a very important role in the sense that it addressed a large number of companies with preliminary results on the potential of applications of CMAs. It indicated new directions of research to CMA scientists (like the need for replacing Cd in aeronautic industry). A program for short-term projects was financed, with the view that exploratory research on specific aspects of CMA applications may supply adequate information to convince industry of the usefulness of our materials. All results nevertheless were judged too premature for the needs of European industry and CMAs could not find any real support from industry. The influence of VIU IT was seminal however in orienting the structure of C-MAC into Research and Application Domains (see report).

Joint Program of Dissemination: The Euroschool

The Euroschool of CMA found its steady regime immediately at its first session in Y1. It was divided in so-called basic and advanced tutorials of 50 min each, with altogether 38 lecturing sessions. Two hours were reserved for a special guest of high reputation. Five Euroschools were organised in total:

1st Euroschool, May 22 – 27, 2006: Phase transformations in metals and alloys

2nd Euroschool, May 21 – 26, 2007: Properties and application of complex metallic alloys

3rd Euroschool, May 26 – 31, 2008: Complex metallic alloys: Surfaces and coatings

4th Euroschool, May 25 – 30, 2009: Mechanical properties of complex metallic alloys

5th Euroschool, May 24 – 29, 2010: Properties of complex metallic alloys: Modelling, simulation and experiment.

As already mentioned, the University of Ljubljana offered in Y3-Y5 a number of ECTS credits to those students who applied and successfully passed an examination during and after the end of the year session.

Joint Program of Dissemination: The series of books on CMAs

Four books were issued after the first four Euroschools (Editor and head of VIU PB: E. Belin-Ferré, CNRS, Paris). World Scientific, Singapore offers them now at reasonable price on its marketing list. Furthermore, another more condensed book was edited by J.M. Dubois and E. Belin-Ferré after Wiley (New York, Berlin) made an offer to publicize the work of CMA-NoE. In total, a very complete coverage of the science and engineering of complex metallic alloys was thus made available.

Joint Program of Dissemination: Knowledge management

One partner (head of VIU KM: T. Latour, CRPHT, Luxemburg) was specifically in charge of knowledge management and work was done along this line during Y1 and Y2. The task was abandoned however when it became obvious that no sufficient mutual understanding could be achieved between experts in information technologies and experts in CMAs. Members of the CMA-NoE preferred to focus at a far less ambitious objective and concentrate on a simple data base listing papers available in the field of CMAs.

Joint Program of Dissemination: News Letter

Two letters were published during the duration of CMA-NoE, which were mailed to about 5000 recipients each.

Joint Program of Dissemination: Organisation of meetings and conferences

A very large number of internal meetings has been organised during the lifetime of CMA-NoE, see list of deliverables. Aside the Euroschool sessions, which were very much international

meetings addressing the international community, the network has organised several international events, or has participated in international meetings organised by others. We can at this stage mention the Euromat conference (Nürnberg, 2006), the 25th Anniversary Jubilee conference (Tel Aviv, 2007), the Aperiodic conference (Liverpool, 2008), the International Workshop on CMAs (Zagreb, 2008), the C-MAC 1 conference (Nancy, 2009), the 11th International Conference on Quasicrystals (Sapporo, 2010). In this respect, the mid-term meeting organised by C. Vahlas on Santorini Island in Greece was also a very successful international meeting because of the participation of key scientists from US, China, India, Japan, and Europe.

Joint Program of Research: The CMA factory

It is not possible to assemble here in few lines the mainstream of results gained over five years by more than 400 scientists (junior and senior) engaged in CMA-NoE. A decisive point however has to be mentioned since it took place in the network from its very beginning, namely the joint effort co-ordinated by VIL A (Metallurgy; director: W. Assmus, Frankfurt University) by a full ensemble of groups capable of growing high quality samples and distributing them after basic characterization to the other groups. This joint activity was very efficiently organised, starting with initial ingots and going to single crystals of very high quality. Several tens of such specimens were grown, and exchanged among partners, including specimens the composition of which was not foreseen at the beginning of the project. Beyond the invaluable scientific merit of such samples, there is no need to mention their integrating role.

Joint Program of Research: New challenging topics

Based on the progress made on the alloys initially foreseen, as well as on the pressure raised by newcomers from partner institutions, the scope of CMA-NoE has smoothly evolved over the years from Al-based CMAs towards more challenging compositions like magnetocaloric alloys, cage compounds, and composites. All new topics, which complemented the programme of the VILs, specifically of VIL C (physical properties; director: H-R. Trebin, University of Stuttgart), have significantly contributed to the paper production of the network. Applications were sorted out and are secured by patents.

Joint Program of Research: Achievements towards applications

The following areas of CMA science and engineering have led us to secure patents: composites, magnetocalorics, thermoelectricity, catalysis, information storage, measurements technology. Altogether, CMA-NoE has contributed 6 patents to the partners IPRs. These patents come in addition to the patents filed before the start of the project on coatings, reduced adhesion and friction, corrosion resistance. In total, the potential for applications of CMAs has been more than doubled by CMA-NoE.

Joint Program of Research: An overview

An overview cannot be given here, in this (too) short summary. The Reader is invited to consult the books mentioned earlier in this summary. He (she) may also be interested in reading the few hundreds of articles issued by the CMA-NoE in the scientific literature, including few articles in Nature, Phys. Rev. Lett., etc. Breakthroughs by the VILs can be listed as follows (this list cannot be exhaustive!):

- VIL A: (director: W. Assmus, Frankfurt University): single grain growth of extremely complex alloys, with thousands of atoms per unit cell;
- VIL B: (director: G. Kreiner, MPG, Dresden): discovery of a new plastic deformation mechanism, involving the contribution of hundreds of atoms (published in Nature Materials);
- VIL C: (director: H-R. Trebin, University of Stuttgart): deeper comprehension of phonon transport and phase transitions between complex phases, thermal storage of

information, thermoelectric behaviour of cage compounds, magneto-caloric materials with improved efficiency, etc.;

VIL D: (director: R. McGrath, University of Liverpool): surface crystallography in association with the unprecedented discovery of very attractive catalytic properties of low cost CMAs, high corrosion resistance of Cr-containing CMAs, etc.

VIL E: (director: C. Vahlas, CNRS, Toulouse): setting-up of a new coating process based on MO-CVD for multinary, metallic coatings, thus opening a new route in coating technology.

VIL F: (director: JP. Celis, KUL, Leuven): solid-state reactivity with applications to microelectronic devices can probably be registered as the major output of this VIL.

Numerous articles were published by all VILs in high standard journals, see report.

Management: Governance

The bodies that were installed to govern the network proved sufficient, as far as self-contentment is concerned. Three executive officers (J.M. Dubois, CNRS, Nancy; L. Schlapbach, EMPA, Zürich; K. Hoehener, TEMAS, Arbon) were in charge of, respectively, the overall management of the network and correspondence with the EC, scientific issues and innovation transfer. They met few times per year with the VIL+VIU directors. The governing board, composed by the partner administrative heads, often, but not always, the heads of the partner institutes, met once a year. The SAC, already introduced above, joined most of the meetings. This system, although pretty light in terms of dedication of human resources, proved sufficient to handle all questions dealt with by the network. It can be regretted however that coupling to the highest level of the headquarters of the major partners, CNRS in particular, proved pretty difficult, or inefficient.

Management: The network office

The administration of CMA-NoE was ran in a brilliant way, to the entire satisfaction of all partners, by Frau A. Gemperli, head of TEMAS, partner 20 in the network. All reports were delivered on time, except for financial matters that were often delayed by the leave of absence of finance officers in CNRS institutes during Summer times, when unfortunately the reports were supposed to be delivered.

Management: Distribution of funds

The distribution of funds was managed by CNRS according to EC standards. We regret that CRPHT, who very efficiently managed the Mission service, has to face today difficulties because of VAT questions that have never been considered fully before by the administrative officers of the EC. Whereas it has been tacitly accepted by the EC i- that the mission service was an original and efficient integration tool for the whole network, and ii- that CRPHT cannot support on its own finances the VAT attached to the mission costs from all partners (about 1.4 M€ in total), it came out at the end of the project that all VAT costs must be fully accounted for by CRPHT to the EC and withdrawn from its eligible costs. This supplementary task – and more importantly, financial loss - imposed to CRPHT goes beyond the financing accepted by the EC for CMA and spoils a great deal of the efforts successfully accepted by our partner in Luxemburg. Hence, we definitely feel that the virtues of a European network (of excellence) have not been fully integrated in the administrative spheres of the EC.

Acknowledgements:

The very substantial support offered by the EC is most gratefully acknowledged. As well, all partners are grateful to the scientific officers and EC technical experts for the kind spirit of assistance and interest shown to this project over the years.

2 Project execution

All results of the NoE CMA are summarized in the confidential final activity report, dated August 14, 2010 which was sent to the EC separately and can be accessed through the CMA website, member's part as well <http://www.cma-ecnoe.net>.

3 Dissemination and use

The knowledge assembled by CMA NoE is available as public literature: patents, articles in scientific journals and books as well as CMA News, electronic News Letters, leaflets. Accessible on

- the NoE CMA home page <http://www.cma-ecnoe.net>
- or via direct access to the NoE CMA knowledge database <http://www.cma-ecnoe.net/CMA/CMAProj.nsf/fmPubsByType?ReadForm&cat=01&count=12&lang=en>