EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

EUROCORES Programme
European Collaborative Research

Smart Structural Systems Technologies (S3T)

MAFESMA Final Report

A.1. Overview of the CRP

CRP Number:	05-S3T-FP001-MAFESMA
CRP Title and Acronym:	Material algoritms, Finite Element methods, Experiments (MAFESMA)
Project Leader (PI 1):	Professor Jan van Humbeeck, Belgium
Principal Investigator 2:	Professor Simo Pekka Hannula, Finland
Principal Investigator 3:	Professor Kalervo Nevala, Finland
Principal Investigator 4:	Professor Jari Koskinen, Finland
Principal Investigator 5:	Dr. Merja Sippola, Finland
Principal Investigator 6:	Dr. Vaclav Novak, Czech Republic
Associated Partner 1:	Professor Sylvain Calloch, France
Associated Partner 2:	Dr. Michel Landa, Czech Republic
Associated Partner 3:	Professor Christian Lexcellent, France
Associated Partner 4:	Professor Etienne Patoor, France
CRP start and end dates:	1/10/2006-30/09/2010
Mid-Term Report submission:	29/01/2009
CRP website:	http://www.fzu.cz/departments/metals/sma/mafesma/

Part B. Progress report

B1. CRP progress and scientific highlights (max. 1500 words)

1. The collaborative work (c.400-750 words)

a. With reference to the CRP objectives and work plan, describe the work undertaken by the CRP and the contribution of each Individual Project to the collaboration in terms of its specific expertise and tasks/responsibilities. How closely did the partners work together?

The main goal of the project was to establish good models for describing and predicting functional behaviour of shape memory alloys in the temperature-stress-strain space. This was later on focussed on a round robin test of different models based on specific dedicated data which were produced at IOP in Prague.
A special website was set-up and a summary of this can be found on:
http://department.fzu.cz/ofm/roundrobin.
All partners contributed to this round-robin.

A very important research area, guided by the Univ. of Oulo was the control of the fibre reinforced composite which included embedded shape memory alloy (SMA) actuators, design of SMA actuators and properties of the magnetic shape memory actuator (MSMA).

The basic structure of an SMA actuated adaptive airfoil and control system components were determined in the project. The aim of the study was to develop a control system suitable for controlling the shape of full –sized wind turbine blades. In the experiments a narrow (100 mm width) airfoil was used. The shape control of the airfoil was tested with two model-based controllers and a PI controller with an anti-windup compensation. The laboratory of mechatronics and machine diagnostics of OULO univ.was responsible especially for the testing the control system components and developing model-based control algorithms. The technical research centre of Finland (VTT) was responsible for investigating integration of the SMA actuators and sensors into the composite structure and manufacturing the specimen. The control issues were discussed also with other project partners (ASCR, MTM, ENSAM, ESSTIN, LMARC, LMSN, TKK) in the workshops during the project.

Another important study was to get practical information about the modeling and designing of SMA actuators for precision mechanics, also guided by the univ. of OULO. The aim was to clarify the possible finite element method (FEM) analysis ways for SMA-actuators. In the study were designed, modeled, and done experimental evaluation of the resistive heating antagonistic actuators. This part of the research work was made in cooperation with the experts of the optomechanics in the (VTT) in Oulu. The laboratory of mechatronics and machine diagnostics was responsible mainly for the study and the experts in VTT Oulu gave feedback and ideas in the meetings. The modelling of SMA actuators was done in co-operation with ASCR and VTT Espoo. Actuator design issues were discussed with ENSAM in the project workshops.

Another topic also guided by OULO univ. was study to define the characteristics of a MSMA actuator and evaluate its suitability for vibration control. The basic properties of MSMA actuator such as stroke, force output, hysteresis, bandwidth and damping were evaluated experimentally in the project. The controllability of a MSMA actuator was studied in closed-loop position and force control tests. In the study a commercial MSMA actuator was used and The laboratory of mechatronics and machine diagnosticsof OULO univ. was responsible for design of the test-bed, development of the control algorithms and experiments. The issues related to control of MSMA were discussed and analyzed with partners ENSAM and TKK in the workshops during the project.

In the Finnish Formafesma project, 10M Ni-Mn-Ga magnetic shape memory specimens were produced and delivered to e.g. the Czech collaborators (ASCR), who measured their elastic properties. The results were published together. Magnetomechancal data of the MSM material was measured at AALTO and delivered to the French partner (LMARC), who then used it as a basis for their internal variable model. At AALTO, the data was used for the MATLAB model made by the ASCR researchers, and by the VTT researchers in the ABACUS model. The fatigue test results were presented to partners in the collaboration meetings, and presented in scientific publications.

2. Scientific highlights (c.400-750 words)

a. Describe the scientific highlights and main achievements of the CRP. What has been the most significant/valuable contribution to knowledge (e.g. results, breakthroughs)?

In the project three alternative control algorithms were compared in the shape control of an adaptive airfoil. The anti-windup compensated (AWC) PI controller was implemented and compared to the model-based controllers in fixed control experiments. According to the results the anti-windup compensation of PI controller improves stability in step responses. The positioning and tracking accuracies of the compensated controller was also better than model-based controllers. In conclusion, the embedded SMA actuators can be controlled successfully with a PI controller if the power limiter is compensated appropriately.

As a result of the study of the modelling and designing of SMA actuators achieved SMA actuators for precision mechanics which fulfil the study objectives excellently. The similar actuator has not been developed for the problem earlier. The measures of the NiTi disk actuator was 0,54 * 20 * 20 mm. and the 1,9 mm. movement range was achieved with the actuator. In the study it was noticed that a complex thermomechanic behaviour of SMA requires utilizing of FEA tools when the SMA elements which are more complex than wire are designed. It is possible to use effectively existing SMA material models only for the modelling of the actuators which utilize the superelastic phenomenon. A lot of simplifications have to be made and have to be restricted only at certain load situations in a analysis of the actuators which are activated with a resistive heating. The FE analysis was a coarse tool which facilitated the search of essential deformation areas, optimization of the shape of the actuator and estimation of the movement range.
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In the study which has concentrated on the properties of the MSMA it was noticed that the PI control is suited for the magnetic memory actuators if the hysteresis has been compensated properly. In force control the hysteresis compensation upraised the maximum operating frequency of the system from 20 Hz (without hysteresis compensation) to 150 Hz. The experimental results also proved that the stiffness and damping of the MSMA actuator are proportional to the control current. The experimental results indicate MSMA being suitable material for active vibration control.

Roundrobin SMA modeling started as a unique collaboration activity among researchers participating in MAFESMA and SMARTer S3T projects at a workshop held in Prague as a collaboration/networking activity in frame of the ESF EUROCORES programme. The workshop was organized with the aim to bring together the experimentalists and modellers within who were working actively on the development of SMA models, their numerical implementation, development of control algorithms for SMA actuated structures and SMA composites.

ESF EUROCORES **S3T modelling session** was organised the “8th European Symposium on Martensitic Transformations” Esomat 2009 in Prague. The researchers from teams involved in the Roundrobin SMA modeling activity presented their simulation results at two special sessions open to other conference participants, the results were collectively discussed and a roadmap to final presentation of the results of the activity in a form of EDP Sciences articles and this website was laid out.

-A new high frequency fatigue testing device for the MSM material was designed and constructed. With this system, there were several cycling tests made, and the 10M Ni-Mn-Ga MSM material demonstrated $2x10^9$ mechanical cycles fatigue life, which is the longest fatigue life for these materials reported by today, and in fact with a strain amplitude of ±1% the world record for any metallic materials.
Magnetomechanical fatigue testing system was also designed and constructed. Magnetomechanical

cycling tests were carried out with this system and the obtained results were published. These tests yielded completely new information information on the fatigue properties of the MSM materials and the mechanism of the fatigue cracking. This information is valuable for the future development and significant for the expected future industrial use of MSM materials. Data of the MSMAs was used for the development and testing of the control systems of MSM actuator (Oulu University group).

b. List up to five of your CRP's most significant joint publications (i.e. involving co-authors from at least two IPs in your CRP or co-authors from other CRPs in the programme).

1. Ruotsalainen, Pasi; Kroneld, Petter; Nevala, Kalervo; Brander, Timo; Lindroos, Tomi; Sippola, Merja: Shape Control of a FRP Airfoil Structure Using SMA-actuators and Optical Fiber Sensors, Solid State Phemomena. Vol. 144 (2009), 196 – 201.
2. H. Seiner, L. Bicanová, P. Sedlák, M. Landa, L. Heller and I. Aaltio, Magneto-elastic attenuation in austenitic phase of Ni-Mn-Ga alloy investigated by ultrasonic methods, Mat. Sci. Eng. A, 521-522, pp. 205-208, 2009.
3. P. Sittner, V. Novak, L. Heller, P. Sedlak, M. Landa, J. Van Humbeeck, Proc. Int. Conf. SMST, DOI: 10.1361/cp ASM int. 2006,p.553-568. …
4. "SMA-modelling", P.Sittner[1,a], L.Heller[1], J. Pilch[1], P.Sedlak[2], M. Frost[2], Y. Chemisky[3], A. Duval[4] , B.Piotrowski[4], T. Ben Zineb[4], E. Patoor[3], F. Auricchio[5] , S. Morganti[5], A. Reali[5], G. Rio[6] , D. Favier[7] , Y. Liu[8], E. Gibeau[9], C. Lexcellent[9] , L. Boubakar[9] D. Hartl[10], S. Oehler[10], D.C. Lagoudas[10] and Jan Van Humbeeck[1,,] in preparation
5. S. Calloch, K. Taillard, S. Arbab Chirani, C. Lexcellent, E. Patoor, " Relation between the martensite volume fraction and the equivalent transformation strain in shape memory alloys," Materials Science & Engineering A, Vol. A438–440, pp. 441–444, 2006.

B.2. Integration of the CRP in the programme (300-600 words)

1. Describe the contribution of your CRP to the EUROCORES programme. What was the place and role of the CRP in the framework of the programme? From a scientific perspective, how well integrated was your CRP in the programme? How would you describe the intensity of interaction between your CRP and other CRPs in the programme?

The subjects were interesting but quite dispersed. Nevertheless there was good interaction at the occasions were meetings were held for all CRP's organised by S3T and where all project leaders were invited.
Especially with the CRP SMARTer a good interaction occurred due to the fact that the alloys applied were of common interest.

The long-term fatigue properties of the magnetic shape memory alloys were studied. Sample materials and data were delivered to the collaborators. In addition, material parameters were experimentally determined for the base and verification of the developed models, and for the design and optimization of the control of MSM actuators

2. Describe the benefit to your CRP of being part of the EUROCORES programme (e.g. achieving critical mass of expertise, scale and scope, visibility, collaborative opportunities, ideas, etc.).

It created the opportunity to compare results (models) of different groups to see in which aspects some models were better or worse. This will help to improve the different models or select the appropriate conditions to obtain optimal results. The interaction with the other CRP gave the opportunity to see in which domains smart materials and approaches could lead to better results.

Modelling expertise and contribution of our collaborators enabled the implementation of the MSMA properties to the models (Matlab and ABAQUS). This also resulted in actual working models applicable for the further research use. There was advantage of the SMA expertise of the Belgian, French and Czech groups for us with the characterization and crystal growth research work, through the mutual meetings and workshops, since the multifunctional MSMa:s also have the SMA effect and there are many similarities in their properties.

B.3. Cross-CRP networking, training and dissemination (max. 750 words)

1. Which networking/training/dissemination activities did you or your CRP members participate in? Indicate how many team members participated in each activity.

> 1. Mafesma kick-off meeting 4.12.2006, Prague, Czech Republic (all)
> 2. Mafesma meeting 15.6.2007 Leuven, Belgium (all)
> 3. Mafesma meeting 10.1.2008, Metz, France (all)
> 4. Mafesma meeting 10-11.9.2008, Helsinki, Finland (all)
> 5. Mafesma meeting 9.3.2009, Leuven, Belgium (all)
> 6. S(3)T 2010 School and Symposium on Smart Structural Systems Technologies 6-9 April 2010, Porto, Portugal: (the PI)
> 7. 2006 September, ESOMAT 2006 conference, Bochum, DE, 3 (participants from our CRP)
> 8. 2007 April, MULTIMAT meeting, Prague, 6
> 9. 2007, Advanced Magn.Mat and their applications seminar, Pori, FI, 3
> 10. 2007 November, US-Europe workshop on adaptive aerospace structures and materials, St. Maximin, FR, 6
> 11. 2008 May, SMA modelling workshop, Prague, 20
> 12. 2008 June-July ICOMAT 2008 conference, Santa Fe, USA, 2,(11 participants from France)
> 13. 2008 June, CIMTEC 2008 conference, Acireale, IT, 3
> 14. 2009 May MAFESMA MSMA course Helsinki, 11
> 15. 2009 September, ESOMAT 2009 conference, Prague, 1 (14 participants from France)
> 16. 2009 December, MRS 2009 Fall meeting, Boston, 2
> 17. 2010 June, E-MRS spring meeting, Strasbourg, FR, 1 ((5 participants from France)
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> 1.

2. **Networking activities.** Describe *the most important networking activity* for your CRP (in terms of impact, outcome, creation of synergy and cooperation within or outside the programme).

> 1. Finland, Aalto University: Cooperation in the developing the iRLOOP SMA material model for a MSM actuator version for magnetic shape memory material. The role of the Aalto University was to produce the experimental verification data for the model.
> 2. Finland, University of Oulu: Cooperation in developing the control of the SMA materials and especially controlling the SMA embedded FRP composites.
> 3. Belgium, KU Leuven: Cooperation with Prof Van Humbeeck's group. Experimental material knowledge about SMAs produced in this group was utilized in model development.
> 4. Czech Republic, Academy of Sciences of the Czech Republic (ASCR): Cooperation with ASCR was intensive in developing SMA material model and producing thermomechanical verification data.
> 5. France, FEMTO-ST, Besançon, cooperation in developing SMA behaviour modelling, interaction with the CRP SMARTer.
> 6. France, LBMS, Brest, cooperation in developing SMA behaviour modelling and control of SMA actuator
> 7. France, LPMM-ENSAM, Metz, cooperation in developing SMA behaviour modelling, control of SMA actuator and development of SMA composite materials, a student from Nancy in VTT for 6 months, a PhD student from ASCR in Nancy and Metz for one year.
> 8. In 2007 the US-Europe workshop on adaptive aerospace structures and materials, St. Maximin, France.

3. **Training activities.** Describe *the most useful training activity* to date (workshop, course, school, etc.) undertaken by senior or junior researchers of your CRP.

a. S(3)T 2010 School and Symposium on Smart Structural Systems Technologies 6-9 April 2010, Porto, Portugal:
b. May 4-7, 2008, Modelling Workshop, Prague, Czech Republic
2. 2007 Multimat meeting Prague, a collection of multidisciplinary SMA related research reports and lectures.

4. **Dissemination activities.** Describe the *most valuable dissemination activity (or activities)* your team undertook, with respect to (i) the scientific community and (ii) the wider public. Describe the outcome and impact of these activities in terms of promoting your field of research and the EUROCORES programme.

1. MAFESMA website: http://department.fzu.cz/ofm/sma//mafesma/
2. Round robin website: http://department.fzu.cz/ofm/roundrobin.
3. Publications in international journals and conference proceedings.
4. ESOMAT 2009 conference (Prague, CZ) provided excellent dissemination, networking and exchange of information within the project consortium and networking with the SMA researchers and with the martensite researchers world wide. There were mutual meetings held and later new research collaboration has been started

5. List the cross-CRP activities your CRP organised or co-organised.

May 4-7, 2008, Modelling Workshop, Prague, Czech Republic: MAFESMA and SMARTer

B.4. Publications, dissemination and outreach

***Important**: In your lists, include only those publications which resulted to a significant extent from work undertaken in the framework of the CRP or from collaboration with other CRPs. Note that all such publications should bear an acknowledgement of the S3T programme.*

In addition:

- List *all* authors.
- Identify with an asterisk (*) publications which acknowledge the EUROCORES programme.
- Underline publications/presentations involving co-authors from at least two IPs within your CRP.
- **Mark in bold publications/presentations involving co-authors from other CRPs in the programme.**

Publications

- Articles

Peer-reviewed articles in journals (published, in press or submitted)

1. Peltonen, Marjaana; Lindroos, Tomi; Kallio, Marke: Effect of ageing on transformation kinetics and internal friction of Ni-rich Ni–Ti alloys. Journal of Alloys and Compounds, vol. 460 (2008), 1 - 2, ss. 237 – 245.
2. Ruotsalainen, Pasi; Kroneld, Petter; Nevala, Kalervo; Brander, Timo; Lindroos, Tomi; Sippola, Merja: Shape Control of a FRP Airfoil Structure Using SMA-actuators and Optical Fiber Sensors, Solid State Phemomena. Vol. 144 (2009), 196 – 201.
3. Karhu, Marjaana and Lindroos Tomi: Long-term behaviour of binary Ti-49.7.Ni(at.%) SMA actuators- the fatigue lives and evolution of strains on thermal cycling, Smart Materials and Structures. Vol. 19 (2010) No:11, 115019, 10p.
4. Frost M.; Sedlak P.; Sippola M. and Sittner P.: Thermomechanical model for NiTi shape memory wires, Smart Materials and Structures, submitted.
5. Lindroos T.; Sippola, M.; Ahola J. and Brander T.: Adaptive airfoil for wind turbine blades, Smart materials and Structures, to be submitted 2010.
6. Xiao-jun Yan and J. Van Humbeeck, "Influence of annealing on recovery stress of cold-worked NiTi wire ", Functional Materials Letters, Vol 2 (2009), 55-60
7. Xiao-jun Yan and J. Van Humbeeck: "Influence on recovery stress of annealed NiTi thin wire during isothermal holding", JAC, 509, (2011) 1001-1006
8. P. Molnar and J. Van Humbeeck: "Recovery stress and shape memory stability in NiTiCu thin wires at high temperatures", accepted by Int. Journal of Materials Research.
9. Xiao-jun Yan and J. Van Humbeeck: "Effect of annealing on strain-temperature response under constant tensile stress in cold-worked NiTi thin wire", submitted to Smart Materials Research
10. Ruotsaleinen , Pasi; Kroneld, Petter; Nevala, Kalervo; Brander, Timo; Lindroos, Tomi; Sippola, Merja: Shape Control of a FRP Airfoil Structure Using SMA-actuators and Optical Fiber Sensors, Solid State Phemomena. Vol. 144 (2009), 196 – 201
11. J. Ahola, T. Makkonen, K. Nevala, T. Lindroos & P. Isto. Model-Based Control of SMA Actuators with a Recurrent Neural Network in the Shape Control of an Airfoil. Solid state Phenomena. Vols. 147 – 149. 2009. pp. 278 – 283
12. J. Ahola, T. Liedes, P. Kroneld & K. Nevala. On magnetic shape memory alloy actuator characteristics. Journal of Vibroengineering. 2009. Volume 11. Issue 3. pp. 443 - 449.
13. P Molnar, P Sittner, V Novak, J Prokleska, V Sechovsky, B Ouladdiaf , S.P. Hanulla, and O Heczko, In-situ neutron diffraction study of magnetic field induced martensite reorientation in Ni-Mn-Ga under constant stress, J. Phys Condensed Matter 20 (2008),104224
14. V. Novák, G.N. Dayananda, P. Šittner, F,M.Fernandes and K. K. Mahesh, On the electric resistance variation of NiTi and NiTiCu SMA wires in thermomechanical cyclic tests, Mat. Sci. Eng. A 481-482 (2008) 127-133

15. P. Molnár, P. Šittner, V. Novák and P. Lukáš, Twinning processes in Cu-Al-Ni martensite single crystals investigated by neutron single crystal diffraction method Mat. Sci. Eng. A 481-482 (2008) 513-517
16. S.Ignacova,T.Cernoch,V.Novak, P.Sittner, The reorientation of the 2H martensite phase in CuAlMn shape memory alloy, Mat. Sci. Eng. A 481-482 (2008) 526-531
17. M. Landa, P. Sedlak, P.Sittner, H.Seiner, L.Heller On the evaluation of temperature dependence of elastic constants of martensitic phases in shape memory alloys from resonant ultrasound spectroscopy studies, Mat. Sci. Eng. A 481-482 (2008) 567-573
18. L. Heller, A.Kujawa,P. Sittner, M. Landa, P. Sedlak, J. Pilch, Quasistatic and dynamical functional properties of ultra thin NiTi wires, E-MRS2007 , European Physical Journal: Special Topics 158 (1), 2008, pp. 7-14
19. P. Molnar, P. Sittner, P. Lukas, S-P Hannula, O. Heczko, Stress induced martensite variant reorientation in magnetic shape memory Ni-Mn-Ga single crystal studied by neutron diffraction, Smart Mater. Struct. 17 (2008) 035014 - 035019
20. P. Šittner, J. Pilch, P.Lukas and M.Landa, H. Seiner, P. Sedlak, B. Malard, L. Heller, In-situ experimental methods for characterization of deformation processes in SMAs, Advances in Science and Technology Vol. 59 (2008) pp 47-56
21. L. Heller, D. Vokoun, D. Majtás, P. Šittner, Thermomechanical characterization of shape memory alloy tubular composite structures, Advances in Science and Technology Vol. 59 (2008) pp 150-155
22. Michal Landa, Petr Sedlák, Hanuš Seiner, Ludìk Heller, Lucie Bicanová, Petr Šittner and Václav Novák, Modal resonant ultrasound spectroscopy for ferroelastics, Appl Phys A, 96 2009, 557-567 DOI 10.1007/s00339-008-5047-4
23. Seiner, H. - Bicanová, L. - Sedlák, P. - Landa, M. - Heller, L. - Aaltio, I.: Magneto-elastic attenuation in austenitic phase of Ni–Mn–Ga alloy investigated by ultrasonic methods. *Materials Science and Engineering A*. 521-522, 2009 pp.205-208.
24. B. Malard, J. Pilch, P. Sittner, V. Gartnerova R. Delville, C. Curfs, D. Schryvers Microstructure and functional property changes in thin NiTi wires shape set by electric current – high energy X-ray and TEM investigations, Functional Materials Letters, Vol. 2, No. 2 (2009) , 45-54, DOI: 10.1142/S1793604709000557
25. L. Heller, P. Šittner, J. Pilch M. Landa, Factors controlling superelastic damping capacity of SMAs , Journal of Materials Engineering and Performance, 18 (2009) 603-611, DOI: D. Vokoun, D. Majtás, M. Frost, P. Sedlák and P. Šittner, Shape memory hooks employed in fasteners, Journal of Materials Engineering and Performance, 18 (2009), 706-710 DOI: 10.1007/s11665-009-9390-1
26. D. Vokoun, M. Beleggia, L. Heller, P. Šittner
Magnetostatic interactions and forces between cylindrical permanent magnets
J. Magn. Magn. Mater. 321 (2009) 3758 - 3763. DOI: 10.1016/j.jmmm.2009.07.030
27. V. Davydov, P. Lukáš, M. Vrána, B. Malard, J. Pilch, V. Maximov, P. Šittner Neutron diffraction study of the stress distribution in steel matrix around active NiTi inserts *Materials Science and Engineering A, 527,2010,* 3310-3316
28. N. Zárubová, J. Gemperlová, A. Gemperle, Z. Dlabáček, P. Šittner, V. Novák In situ TEM observation of stress-induced martensitictransformations and twinning processes in CuAlNi single crystals *Acta Materialia 58 (2010), 5109-5119.*
29. R. Delville, B. Malard b, J. Pilch, P. Sittner, D. Schryvers Microstructure changes during non-conventional heat treatment of thin Ni–Ti wires by pulsed electric current studied by transmission electron microscopy *Acta Materialia 58 (2010) 4503–4515*
30. J. Kopeček, K. Jurek, M. Jarošová, J. Drahokoupil, S. Sedláková-Ignácová, P. Šittner, V. Novák
The preparation of oriented samples of ferromagnetic shape memory alloy CoNiAl
Mat. Sci. Eng. 7 (2010) 012013(1) - 012013(8).
31. Frost, M., Sedlák, P., Sippola, M., Šittner, P., *Thermomechanical model for NiTi shape memory wires*, Smart Materials and Structures 19 (9), art. no. 094010, 2010
32. R. Delville, B. Malard, J. Pilch, P. Sittner, D. Schryvers Transmission electron microscopy investigation of dislocation slip during superelastic cycling of Ni–Ti wires *International Journal of Plasticity 27 (2011) 282–297*

33. Frost, M., Sedlák, P., *Modeling of Two-dimensional Thermomechanical Loading of NiTi Wires*, EDP Sciences, in print
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35. B. Malard , J. Pilch, P. Sittner, R. Delville, C. Curfs, In-situ investigation of the fast microstructure evolution during electropulse treatment of cold drawn NiTi wires, Acta Materialia , in print
36. J.Y. Gauthier, C. Lexcellent, A. Hubert, J. Abadie, N. Chaillet, "Modeling Rearrangement Process of Martensite Platelets in a Magnetic Shape Memory Alloy Ni2MnGa Single Crystal under Magnetic Field and (or) Stress Action", Journal of intelligent Material Systems and Structures, vol.8, no3, pp. 289-299, 2007.
37. C. Collard, T. Ben Zineb, E. Patoor and M. Ouadi Ben Salah, "Micromechanical analysis of precipitates effect on shape memory alloys behaviour", Materials Science and Engineering: A, 2008, Vol. 481-482, Pages 366-370.
38. J.Y. Gauthier, A. Hubert, J. Abadie, C. Lexcellent, N. Chaillet, "Non-linear Hamiltonian modelling of Magnetic Shape Memory Alloy based actuators", Sensors and Actuators A: physical, vol. 141 (2), pp. 536-547, 2008.
39. C. Lexcellent, E. Gibeau, "A short review of shape memory alloys thermemechanical models", Solid State Phenomena, Vol. 138, pp. 355-366, 2008.
40. C. Lexcellent , F. Thiebaud, "Determination of the phase transformation zone at a crack tip in a shape memory alloy exhibiting asymmetry between tension and compression", Scripta Mat. 59, pp. 321-323, 2008.
41. S. Calloch, K. Taillard, S. Arbab Chirani, C. Lexcellent, E. Patoor, " Relation between the martensite volume fraction and the equivalent transformation strain in shape memory alloys," Materials Science & Engineering A, Vol. A438–440, pp. 441–444, 2006.
42. K. Taillard, S. Arbab Chirani, S. Calloch, C. Lexcellent, "Equivalent transformation strain and its relation with martensite volume fraction for isotropic and anisotropic shape memory alloys", Mechanics of Materials, Vol. 40, pp. 151-170, 2008.
43. K. Laverhne Taillard, S. Calloch, S. Arbab Chirani, C. Lexcellent, Multiaxial Shape Memory Effect and Superelasticity, Strain, Vol. 45, pp. 77-84, 2009.
44. L. Saint Sulpice, S. Arbab Chirani, S. Calloch, "Super-elastic behavior of shape memory alloys under proportional cyclic loadings," Materials Science & Engineering A, 2008, Vol. 481-482, Pages 174-177.
45. T. Bouraoui, F. Jemal, T. Ben Zineb, "Tensile properties of a Fe-32Mn-6Si shape memory alloy", Strength of Materials, 2008, Vol. 40, No. 2, Pages 55 – 65.
46. MR Laydi C Lexcellent, Yield criteria for shape memory materials: convexity conditions and surfaces transport, Mathematics and Mechanics of Solids, Vol. 15, Issue 2, pp. 165-208**,** 2010.
47. V Taillebot, S Divinski, C Lexcellent J Bernardini DL Beke, Towards a correlation between high-temperature creep and volume diffusion for equiatomic Ni-Ti alloys, Defect and Diffusion Forum Vols 280-281 pp 97-104(2008)
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49. J. Abadie, N. Chaillet, C. Lexcellent, Modeling a new SMA micro-actuator for active endoscopy applications Mechatronics, Vol. 19 (2009) pp 437-442
50. N. Siredey-Schwaller, A. Eberhardt and P. Bastie. Parameters influencing the fatigue life of a Cu–Al–Be single-crystal shape memory alloy under repeated bending. Smart Mater. Struct. 18 (2009) 025014
51. M. Collet, M. Ouisse, E. Foltete and C. Lexcellent Isothermal and anisothermal implementations of 2D shape memory alloy modeling for transient impact response calculation, Smart Mater. Struct. 18 (2009) 125019 (12pp) doi:10.1088/0964-1726/18/12/125019
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44. *Aaltio, O. Söderberg, M. Friman, I. Glavatskyy, Y. Ge, N. Glavatska and S.-P. Hannula,* Determining the liquidus and ordering temperatures of the ternary Ni-Mn-Ga and quaternary Ni-Mn-Ga-Fe/Cu alloys, The 8th European Symposium on Martensitic Transformations - ESOMAT 2009, Prague, Czech Republic on September 7 - September 11, 2009. Oral presentation (Aaltio).
45. *Y. Ge, N. Zárubová, Z. Dlabáček, I. Aaltio, O. Söderberg, S-P. Hannula,* In-situ TEM straining of tetragonal martensite of Ni-Mn-Ga alloy, The 8th European Symposium on Martensitic Transformations - ESOMAT 2009, Prague, Czech Republic on September 7 - September 11, 2009. Oral presentation (Zárubová).
46. *Aaltio, Y. Ge, X. Liu, O. Söderberg, J. Tellinen, A. Sozinov and S.-P. Hannula,* Effect of magnetomechanical cycling on 10M Ni-Mn-Ga magnetic shape memory material, ICOMAT 2008, Santa Fe, USA, June-July 2008, oral presentation (*Aaltio*).
47. *O. Söderberg, I. Aaltio, Y. Ge, X.W. Liu, S.-P. Hannula*, Recent developments of magnetic SMA, CIMTEC 2008, The 3rd International Conference on Smart Materials, Structures and Systems, Acireale Sicily Italy, 8-13 June 2008, invited presentation (Söderberg).
48. *O. Söderberg, Y. Ge, I. Aaltio, O. Heczko and S.-P. Hannula*, Ni-Mn-Ga multifunctional compounds, ESOMAT06, European Symposium On Martensitic Transformations and Shape-Memory Bochum, Germany 10-15 September 2006. Invited lecture (Söderberg).
49. *Aaltio, I., O. Söderberg, Y. Ge, O. Heczko and S-P. Hannula*, Recent developments in the understanding of the magnetic shape memory effect in Ni-Mn-Ga alloys, oral presentation in Seminar on Advanced Magnetic Materials and Their Applications, Pori 9-11.10.2007, Prizztech, Pori, Finland, oral presentation *(Aaltio)*
50. *Hannula S-P., Aaltio I., Ge Y., and Söderberg O., Magnetic Shape Memory Effect in Ni-Mn-Ga Alloys, MRS Korea Fall Meeting, 11-12.11.2010, Muju, Korea. Plenary presentation (Hannula)*

- Posters

1. Karhu, Marjaana & Lindroos, Tomi : Long-term behaviour of binary Ni-Ti wires
2. School and symposium on smart structural systems technologies, S(3)T2010, Porto, Portugal 6-9 April 2010. S(3)T2010 School and symposium on smart structural systems technologies. R. Barros & A. Preumont. Porto, Portugal (2010), 530
3. Y. Chemisky, V.-L. Tahiri, A. Eberhardt, E. Patoor, “Numerical modelling of a shape memory alloy/elastomer composite” MHM 2007, Modelling of Hérogeneous Materials, Prague, Juin 2007.
4. B. Piotrowski, A. Duval, Y. Chemisky, T. Ben Zineb, A. Eberhardt, E. Patoor, “Modelling of SMA with elastic-plastic inclusions”, Workshop, Modelling of SMAs and SMA Actuated Structure, ESF EUROCORES programme Smart Structural Systems Technologies (S3T), Prague, Czech Republic, May 4-7, 2008.
5. N. Siredey-Schwalle, B. Malard, A. Eberhardt, E. Patoor, P. Bastie, Study of the fatigue breakdown of Cu-Al-Be Shape Memory Alloy wires using hard X-ray diffractometry, E-MRS Spring Meeting, June 7-11, 2010, Strasbourg, France.
6. *I. Aaltio, Y. Ge, H. Pulkkinen, O. Söderberg, S-P. Hannula,* High-frequency strain-controlled cycling of Ni-Mn-Ga magnetic shape memory material, S3T Workshop, Smart Structural System Technologies, April 2010, Porto, Portugal. Poster presentation (Ge).
7. *Y. Ge, I. Aaltio, O. Söderberg, S-P. Hannula,* X-ray diffraction reciprocal space mapping study of 10M modulated crystal structures in 10M Ni-Mn-Ga martensitic phase, The 2nd International Conference on Ferromagnetic Shape Memory Alloys, ICFSMA'09, Bilbao, Spain, 1-3 July, 2009. Poster presentation (Ge).
8. *Y. Ge, I. Aaltio, O. Söderberg, and S.-P. Hannula*, X-ray and High Resolution Transmission Electron Microscopy Studies of Tetragonal Martensite of Ni-Mn-Ga Alloys, ICOMAT 2008, June 29 – July 05, 2008, Santa Fe, USA, poster presentation (*Ge*).
9. *I. Aaltio , M. Lahelin, O. Söderberg, O. Heczko, B. Löfgren, Y. Ge, J. Seppälä and S.-P. Hannula*, Temperature dependence of the damping properties of Ni-Mn-Ga alloys, ESOMAT06, European Symposium On Martensitic Transformations and Shape-Memory Bochum, Germany 10-15

September 2006. poster presentation (*Aaltio*).

10. *Y. Ge, O. Heczko O. Söderberg and S.-P. Hannula*, Comparison of different methods for studying magnetic domains in Ni-Mn-Ga martensites, ESOMAT06, European Symposium On Martensitic Transformations and Shape-Memory Bochum, Germany 10-15 September 2006. poster presentation (*Ge*).

- Other (*please define*)

1. J. Ahola, T. Makkonen, K. Nevala & P. Isto. Comparison of Position Control Algorithms of Embedded Shape Memory Alloy Actuators, oral presentation (Ahola). IEEE International Conference on Mechatronics. 2009. Malaga. Spain.
2. J. Ahola, T. Liedes, P. Kroneld & K. Nevala. On magnetic shape memory alloy actuator characteristics, oral presentation (Kroneld). Vibroengineering 2009. 8th International Conference 16-18 September. 2009. Klaipeda. Lithuania.
3. J. Ahola. Comparison of position control algorithms of embedded shape memory alloy actuators. Presentation at MAFESMA meeting 9 March 2009. Leuven, Belgium.
4. J.-P. Teeriaho, J. Ahola, K. Nevala. Muistimetallitoimilaitteiden mallinnus ja suunnittelu tarkkuusmekaniikkaan, oral presentation. The 10th Finnish Mechanics Days. December 3-4, 2009. Jyväskylä. Finland.
5. J. Ahola. Model Based Control of SMA Actuators with a Concurrent Neural Network in the Shape Control of an Airfoil. Presentation at MAFESMA meeting. 10 January 2008. Metz, France.
6. J. Ahola, T. Makkonen, K. Nevala, T. Lindroos & P. Isto. Model-Based Control of SMA Actuators with a Recurrent Neural Network in the Shape Control of an Airfoil, oral presentation (Ahola) The 4th international conference mechatronic systems and materials. 14.-17.7.2008. Bialystok. Poland.
7. J. Ahola & J.-P. Teeriaho. Material tests and development of positioning device. Presentation at MAFESMA meeting. 10 - 11 September. 2008. Espoo, Finland.