GENERAL INFORMATION

Workshop fee - what is included?
Technical Meetings
Poster Session and Reception
Abstract Booklet
Breakfasts (Main Campus Cafeteria), Lunches (Faculty Club, except Thursday) and Coffee Breaks
Workshop Materials
Guided Boat Tour of Boğaziçi on Tuesday, June 22.
Conference Banquet on Tuesday, June 22.
Historical Tour of Istanbul on Thursday, June 24. (Lunch on June 24 will not be served)

Workshop Website
home.ku.edu.tr/~sma

On-Site Registration
Registration Office
Koc University, Faculty of Engineering

Poster Size
Poster size should not be larger than:
180cm×90cm

Poster Awards
The first three runners will be awarded with cetificates.

Lunches
Lunches will be served at Koc University Faculty Club.

Wi-Fi Connection
Free Wi-Fi connection will be available.

Policy on Audio and Video Recording
Recording of workshop talks and posters is strictly prohibited.
**Accommodation**

**Koc University’s Dormitories**

**Main Campus Address:** Koc University, Rumeli Feneri Yolu, 34450 Sariyer/Istanbul

**Istinye Campus Address:** Koc University Çayır Cd. No: 5 Istinye-Istanbul

**Bilek Hotel Address:** Eski Buyukdere Caddesi No:29 4. Levent/Istanbul-TURKEY

Phone: +90 212 3242024

Accommodation is not included in the workshop fee.

**Public Transportation Information**

The possibilities are bus, boat, taxi and subway. The systems are relatively simple once you get to use it. The major destinations are Eminonu, Besiktas and Taksim. Yet, 2-3 days may be a bit short to decipher the system (unfortunately, it is not user friendly). We suggest you to take a taxi which is abundant and relatively cheap compared to Europe. The modern subway in Istanbul is relatively new and extends to a very limited area.

**Buses:** The ticket is for getting on the bus, and it is not linked to your destination so there is no need to explain to someone where you are going. The ticket ("otobus biletli" or simply "bilet") cannot be purchased on the bus. At sizeable bus stops there is a booth that sells bus tickets. Often other booths which sell soft drinks and newspapers also sell bus tickets. It is convenient to buy a group of tickets so that, if you need a bus at a small bus stop, you avoid the problem of trying to find a ticket. The price of a one-way trip is 1.5 TL and tickets can be purchased in groups of 5 for 7.5TL. There are two types of buses operating in Istanbul: buses run by the municipality (green or red colored buses) and private buses (blue colored). Private buses offer the advantage of paying by cash on the bus if you are short of tickets. Each bus has a destination sign on the front and on the right side (next to the entrance door) which describes its route. These signs also have route numbers. The bus-stops usually have the location displayed on the sign. With a city map, you can follow where the bus is going by noting these signs.

**Taxis:** Taxis are plentiful in Istanbul and are inexpensive by US and European standards. In this regard, Istanbul is easy for newcomers. No matter where you happen to get lost or run out of steam, you are likely to find an empty taxi to take you back to familiar surroundings. All taxis use meters; be sure the driver turns the meter on. The cost is what the meter says. Drivers always recognize the major part of the city you want to go to (i.e. Taksim) and need that information in order to take you to some particular address. Returning to the campus is accomplished by asking for KOC UNIVERSITY, Main Campus. Taxi driver will now Sariyer and from there even without any instruction he will be able to find the university campus by following signs and/or asking people. So at least record the names Sariyer and Koç University (The letter “ç” in Koç is pronounced as “ch” in chair).

**Boats:** The boat dock is at Sariyer. This is a very pleasant way to travel, less crowded during rush hour than one would expect, and also a rapid way to get downtown on a weekday morning. The schedule is posted at the dock, inside the waiting room. You purchase a token
from the ticket window at the dock. If the boat comes and ticket windows are closed, then a boat worker will sell you the token. Going south, the final destination is Eminonu. These boats dock at a particular landing. To return from there, study the schedule posted inside the waiting room and look for boats that return to Sariyer.

Please note that taxi fee from airport to accommodation sites is around 70TL (Turkish Liras).

**Turkish Currency**
Money exchange can be done at the exchange offices and banks.
1 USD is around 1.6 TL (Turkish Liras)
1 Euro is around 2 TL.
We advise that you change some money at the airport.

**Banking Hours & Shopping**
Banks are open weekdays from 09:00 to noon and from 13:30 to 16:30. USD and major credit cards are widely accepted. Shops are generally open from 09:00 to 19:00, Monday through Saturday. Shops are closed on Sundays. However, in Istanbul, Ankara, Izmir and resort areas, the shops and shopping malls are open daily from 10:00 to 21:00/22:00.

**Tipping**
Though service charges may be included in general, it is customary to show your appreciation to hotel staff, to the waiters, if you feel satisfied. We suggest the following tipping scale: Hotels staff 5TL, usually 10% of the bills at restaurants (you are not expected to tip more than 30-40TL in any case) and a round up at taxis.

**Phone Number that can be called in case of emergency**
Police: 155
Emergency: 112
Koc University’s Secretary Office: +90 (212) 338-2636, +90 (212) 338-3745
There are public phones in the Student Center, Level -1, next to the University Post Office (marked as PTT) and the Migros Supermarket. You will need to purchase a phone card at the post office to use public phones.
Istanbul (spelled İstanbul in Turkish) is the largest city in Turkey, and was the capital city of the Ottoman Empire until 1923. The city has been known since ancient times by the older names Byzantium and Constantinople. Being a seaport, Istanbul is the main trade center of Turkey.

Istanbul is divided in three regions by the north-south Bosphorus Strait (İstanbul Boğazı), the dividing line between Europe and Asia, the estuary of the Golden Horn (Haliç) bisecting the western part and the Sea of Marmara (Çanakkale Boğazı) forming a boundary to the south. Most sights are concentrated in the old city on the peninsula of Sultanahmet, to the west of the Bosphorus between the Horn and the Sea. Across the Horn to the north are Galata, Beyoğlu and Taksim, the heart of modern Istanbul, while Üsküdar and Kadıköy are the major districts on the comparatively less-visited Asian side of the city. The Black Sea forms the northern boundary of Istanbul. The city is actually in both Europe and Asia, but its important part is in Europe. Its population is between about 14 million people, making it one of largest cities in Europe.

Its original name was Byzantion in the Greek language, known as Byzantium in the Latin language. Byzantium was originally settled as a colony by Greeks from Megara in 667 BC, and named after their king, Byzas. In 196 AD, Byzantium was destroyed by the Romans, then rebuilt by the Roman Emperor Septimius Severus. Constantine the Great thought this city was in beautiful location, and in 330, moved the capital of the Empire from Rome to there, as New Roma, renaming the city Constantinople (Constantinopolis in the Greek language), after his name.

When the Roman Empire was later divided into two, the East Roman Empire was known as the Byzantine Empire, and had its capital in Constantinople. Although it was captured by Crusaders for a time, it continued as one of political, cultural, religious and economical centers of Europe until it finally fell to the Ottoman Sultan Mehmed the Conqueror in 1453.

Istanbul was the capital of Ottoman Empire until the founding of the Turkish Republic in 1923, when the capital was transferred to Ankara.

Although thousands of years have passed, Istanbul still maintains its geographical importance. Today Istanbul is a huge metropolis connecting continents, cultures, religions and being home to fourteen million people;
and one of the greatest business and cultural center of the region.

Istanbul is not explorable within a week or a month, but there are some popular places to visit so as to say that you have been to Istanbul. Some of them are as follows;

- Museums
- Haghia Sofia (Aya Sofya)
- Topkapi Palace (Topkapi Sarayi)
- Sultanahmet Mosque (Sultanahmet Camii, aka Blue Mosque)
- Chora Church
- Byzantine Hippodrome
- Basilica Cistern (Yerebatan Sarnici)
- The Museum of Archeology
- Museum of Modern Art
- Dolmabahce Palace
- Grand Bazaar
- Spice Bazaar
- Beyoglu - Istiklal Street
- Ortakoy
- Princes' Islands
- Constantine's Column (Çemberlitas)
- Galata Tower
- Maiden Tower
- Golden Horn
- City Walls
- Galata Whirling Dervish Hall (Galata Mevlevihanesi)
- Aşyan Museum
- Caricature And Humor Arts Museum
- Mosaics Museum
- Sadberk Hanım Museum
ORGANIZATION COMMITTEE

It is our pleasure to welcome all participants of the “Special Workshop on Shape Memory Alloys: Current State and Future Developments” in Istanbul. We thank all participants, session chairs, local organizing and international advisory committee for their efforts in organizing this workshop.

Demircan Canadinc, Koc University, TURKEY (CO-CHAIR)
Ibrahim Karaman, Texas A&M University, USA (CO-CHAIR)
Benat Kockar, Hacettepe University, TURKEY (CO-CHAIR)
Huseyin Sehitoğlu, University of Illinois at Urbana-Champaign, USA
Dimitris C. Lagoudas, Texas A&M University, USA
Haluk E. Karaca, University of Kentucky, USA
Hans J. Maier, University of Paderborn, GERMANY

We are also thankful to our sponsors for their support in organizing this workshop.

NSF (US National Science Foundation)
TUBITAK (The Scientific and Technological Research Council of TURKEY)
International Institute for Materials for Energy Conversion (IIMEC) at Texas A&M University
INTERNATIONAL ADVISORY COMMITTEE

J. Van Humbeeck, University of Leuven - Belgium

T. Kakeshita, Osaka University – Japan

G. Olson, Questek Inc. – USA

C. Lexcellent, Universiy of France-Comte – France

S. Carilli, American Hospital – Turkey

Y. Chumlyakov, Siberian Physical Technical Institute - Russia
SOCIAL EVENTS

Sunday, June 20

16.00-20.00................ Registration, Koc University

Monday, June 21

9.00-9.45....................Workshop Opening, Koc University

Tuesday, June 22

16.30-18.30...............Boat Tour of Boğaziçi (Starts at Sarıyer Port)
18.30-21.00...............Workshop Banquet in Adile Sultan Palace
21.00-22.00..............Evening Boat Tour of Boğaziçi and Return to Sariyer

Thursday, June 24

11.00-19.00..............Historical Tour of Istanbul

Adile Sultan Palace

The view of Bosphorus from Adile Sultan Palace
HISTORICAL TOUR (Thursday, June 24, 11.00-19.00)

First place to visit is the Hippodrome Square in Old City, which was built by the Roman Emperor Septimus and it was the centre of Byzantium’s social life for a 1000 years and of Ottoman’s for another 400 years. It was the scene of countless political and military events during the long life of this city (Byzantine).

Then we will proceed to the Sultan Ahmet Camii which is also called the Blue Mosque. It is one of the most famous monuments in both Turkish and Islamic worlds, being the only mosque built with 6 minarets. It is decorated with very nice “Iznik” tiles, worth seeing (Ottoman).

Haghia Sophia was built by Constantine the great and considered as a masterpiece of Byzantine art. Its first construction dates back to the end of the 4th century. Haghia Sophia served as a church for 916 years and as a mosque for 477 years until Ataturk’s orders converted it into a museum, now displaying the pieces both from Christianity and Islam (Byzantine).

Time at leisure for lunch.

Topkapi Palace should be seen while you are in Istanbul. In 1465, Sultan Mehmet, the conqueror of Istanbul, ordered the construction of this Palace. The Ottoman Sultans lived in and administered the Palace until the 19th century.

This palace was the imperial residence of the Ottoman sultans and it is the most extensive and fascinating monument of Turkish civil architecture in existence. In addition to its historical and architectural interest, it houses extraordinary collections of porcelain, armour, fabrics, jewellery, miniatures, calligraphy and many other precious objects that once belonged to the sultans and their court.

One of the most intriguing aspects of life in the ancient orient is the Harem. Topkapi Palace Harem has been open to the public for many years. A guide will take us through these sections and also to the newly designed treasury exhibit, one of the richest in the world. Treasury section is included, Harem section is included.
MAP OF ISTANBUL

- Koç University Main Campus
- Koç University İstinye Campus
- Atatürk International Airport
- Ancient City
- Levent - Business District
- Maslak - Business District
- Taksim Square - City Centre
TECHNICAL PROGRAM
Technical Program

MONDAY, June 21

8:00 – 9:00  Breakfast (Main Campus Cafeteria) and Registration
9:00 – 9:20  Welcome Speech, President of Koc University
9:20 - 9:45  Welcoming Remarks and Workshop Details

9:45 – 10:15  "Dislocations, Martensitic Transformations and Functional Fatigue of Shape Memory Alloys"
G. Eggeler¹, O. Kastner¹, J. Frenzel¹, T. Simon¹, Ch. Somsen¹, A. Dlouhy²
¹Institute for Materials, Ruhr University Bochum, 44801 Bochum, Germany
²Institute of Physics of Materials, ASCR, Zizkova 22, 616 62 Brno, Czech Republic

10:15 – 10:35  "On the Role of the Dislocation Slip in Superelastic Cycling of NiTi"
P. Sittner¹, R. Delville², J. Pilch³, L.Heller¹, V. Novak¹
¹Institute of Physics of the ASCR, Na Slovance 2, 182 21, Prague, Czech Republic
²EMAT, University of Antwerp, Groenenborgerlaan 171, B-2020 Antwerp, Belgium

10:35 – 10:55  "Nanostructured Shape Memory Alloys"
T. Waitz², W. Pranger³, T. Antretter³, F.D. Fischer³, G. Steiner³, M. Peterlechner³
¹Physics of Nanostructured Materials, Faculty of Physics, University of Vienna Boltzmanngasse 5, 1090 Vienna, Austria
²Materials Center Leoben Forschung GmbH, Roseggerstraße 12, 8700 Leoben, Austria
³Institute of Mechanics, Montanuniversität Leoben, Franz-Josef-Straße 18, 8700 Leoben, Austria

10:55 – 11:10  Coffee Break

11:10 – 11:30  "The Role of Symmetry, Intergranular Constraint and Texture Evolution on Elastic Strain Anisotropy in Polycrystalline Martensitic NiTi"
R. Vaidyanathan¹, S. Qiu¹, O. Benafan¹, B. Clausen², S.A. Padula II³ and R.D. Noebe³
¹Advanced Materials Processing and Analysis Center; Mechanical, Materials and Aerospace Engineering, University of Central Florida, Orlando 32816, USA
²Los Alamos National Laboratory, Los Alamos 87545, USA
³Materials and Structures Division, NASA Glenn Research Center, Cleveland 44135, USA

11:30 – 11:50  "Some Factors Affecting the Transformation Characteristics of Shape Memory Alloys"
Yong Liu and Mehrdad Zarinejad
School of Mechanical and Aerospace Engineering, Nanyang Technological University, Nanyang Avenue, Singapore 639798

11:50 – 12:10  "Morphology and Crystallography of Self-accommodated B19’ Martensite in Ti-Ni Shape Memory Alloys"
Minoru Nishida¹, Tomohiro Nishiura³, Tomonari Inamura²
¹Department of Engineering Sciences for Electronics and Materials, Faculty of Engineering Science, Kyushu University, Kasuga, Fukuoka, 816-8580
²Precision and Intelligence Laboratory, Tokyo Institute of Technology, 4259 Nagatsuta, Midori-ku, Yokohama 226-8503, JAPAN

12:10-12:25  Discussion of the Papers in Session1-Part1

12:25 – 13:50  Lunch (Koc University Faculty Club)
13:50 – 14:15
E. Patoor¹, Y. Chemisky², A. Duval³, B. Piotrowski³, T. Ben Zineb³
¹LPMM, Arts et Métiers Paris Tech Arts et Métiers ParisTech, 4, rue Augustin Fresnel 57078 Metz, France
²Texas A & M University, 733 H. R. Bright Building, College Station, TX 77843-3141, USA
³LEMTA, Nancy University, CNRS, France Nancy University, 2 rue Jean Lamour, 54500 Vandoeuvre-les-Nancy, France

14:15 – 14:35
“Constitutive Equations for Martensitic Reorientation and Detwinning in Shape-Memory Alloys”
Prakash Thamburaja and Pan Haining
Department of Mechanical Engineering, National University of Singapore, Singapore 117576

14:35 – 14:55
“Numerical and Experimental Analysis of Martensitic Transformation Localization on a Superelastic Cu-based SMA Multicrystal”
Tarek Merzouki¹,², Christophe Collard¹, Nadine Bourgeois¹, Tarak Ben-Zineb², Fodil Meraghni¹
¹Laboratoire de Physique et M écanique des Matériaux (LPMM), CNRS, Université Paul Verlaine de Metz, Arts et Métiers ParisTech, 4 rue Augustin Fresnel, 57078 Metz, France
²Laboratoire d’Energétique et de M écanique Théorique et Appliquée (LEMTA), CNRS, Nancy University, 2 rue Jean Lamour, 54500 Vandoeuvre-les-Nancy, France

14:55 – 15:15
“Microstructural Modeling of Incomplete Strain Recovery in Titanium Nickelide due to Microplasticity with Isotropic and Translational Hardening”
A.E.Volkov, M.E.Evard
Saint-Petersburg State University, Mathematical and Mechanical Faculty, NIIMM, pr. Universitetsky, 28, Stary Petergof, 198504 Saint-Petersburg, Russia

15:15-15:25
Discussion of the Papers in Session2–Part 1

15:25 – 15:40 Coffee Break

15:40 – 16:00
“Determination of Phase Transformation Surfaces around the Crack Tip at the Interface of a Bimaterial made of a Shape Memory Alloy and an Elastic Medium”
Mohamed Rachid Laydi, Christian Lexcellent
FEMTO-ST, Département de M écanique Appliquée, 24 rue de l’Epitaphe, 25000 Besançon, France

16:00 – 16:20
“Analysis of the Deformation Stage Prior the Superelastic Localised Tensile Stress Plateau of a Ti-50.6at%Ni”
D. Favier¹, H. Louche¹,², Y. Liu³, L. Orgéas¹, P. Schlosser¹,²
¹Université de Grenoble/CNRS, 3SR, BP 53, 38041 Grenoble Cedex 09, France
²Université de Savoie, SYMME, BP 80439, 74944 Annecy le Vieux Cedex, France
³The University of Western Australia. School of Mechanical Engineering, Crawley, WA 6009, Australia

16:20 – 16:40
“Role of Loading Time in the Deformation Patterns of Shape Memory Alloys”
Qingping Sun and Yongjun He
Department of Mechanical Engineering, The Hong Kong University of Science and Technology, Hong Kong, China
Technical Program

16:40 – 17:00
“Non-Monotonic Two-Way Shape Memory in Titanium Nickelide”
A.Motorin, G.Nakhatova, A.Razov
Saint-Petersburg State University, Faculty of Mathematics and Mechanics, Universitetskii pr., 28, Staryi Petergof, St-Petersburg, 198504, Russia

17:00 – 17:20
“The Effect of Irradiation on Microstructure and Phase Transformation of Shape Memory Alloys”
Uner Colak
Hacettepe University, Nuclear Engineering Department, Beytepe 06800 Ankara, Turkey

17:20 - 17:40
Discussion of the Papers in Session2–Part2

19:00 - 21:00 Poster Session and Reception (Koc University Open Pool)

1. “Effect of Time Scales on Hysteresis Damping in Superelastic NiTi Shape Memory Alloys”
Qingping Sun and Yongjun He
Department of Mechanical Engineering, The Hong Kong University of Science and Technology, Hong Kong, China

2. “Morphing Laminar Wing with Flexible Extrados Powered by Shape Memory Alloy Actuators”
V. Brailovski, P. Terriault, D. Coutu, and T. Georges
École de Technologie Supérieure, 1100, Notre-Dame Street West, Montreal (Quebec), H3C 1K3 Canada

3. “Effect of Heat-Treatment on the Mechanical Behavior of Ni_{26.9}Ti_{50.5}Pd_{25} Polycrystals at Elevated Temperatures,”
J. Köhler¹, T. Niendorf¹, H.J. Maier¹, K. Atli², I. Karaman²
¹Lehrstuhl für Werkstoffkunde (Materials Science), University of Paderborn, Pohlweg 47-49, 33098 Paderborn, Germany
²Department of Mechanical Engineering, Texas A&M University, MS 3123, College Station, TX 77843, USA

4. “Competing Mechanisms of Phase Transformation, Plasticity and Creep in High Temperature Shape Memory Alloys”
J.A. Monroe¹, I. Karaman¹², P. K. Kumar¹, D.C. Lagoudas¹²³, R.D. Noebe², G.Bigelow⁴, S.A. Padula II⁴
¹Department of Mechanical Engineering, Texas A&M University, MS 3123, College Station, TX 77843, USA
²Materials Science and Engineering Interdisciplinary Graduate Program, Texas A&M University, College Station, TX 77843, USA
³Department of Aerospace Engineering, Texas A&M University, College Station, TX 77843, USA
⁴NASA Glenn Research Center, 21000 Brookpark Rd., Cleveland, OH 44135, USA

5. “Improved Dimensional Stability and Cyclic Response of Ultrafine Grained NiTiPd Shape Memory Alloys”
K.C. Atli¹, B.E. Franco¹, I. Karaman¹, R.D. Noebe²
¹Department of Mechanical Engineering, Texas A&M University, MS 3123, College Station, TX 77843, USA
²NASA Glenn Research Center, 21000 Brookpark Rd., Cleveland, OH 44135, USA

6. “Anomaly of Critical Stress in Stress-Induced Transformation of NiCoMnIn Metamagnetic Shape Memory Alloy”
Xiao Xu¹, Wataru Ito¹, Rie Y. Umetsu², Ryosuke Kainuma³, and Kiyohito Ishida¹
¹Department of Materials Science, Graduate School of Engineering, Tohoku University, Aoba-yama 6-6-02, Sendai 980-8579, Japan
²Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, Katahira 2-1-1, Sendai 980-8577, Japan
³Department of Mechanical Engineering, Texas A&M University, MS 3123, College Station, TX 77843, USA

7. “Anelasticity and Reversible Villary Effect in NiMn-In-Co Metamagnetic Shape Memory Alloy”
D. Salas¹, S. Kustov¹, I. Golovin², E. Cesari¹
¹Dep. Física, Univ. Illes Balears, Cra Valldemossa, km 7.5, Palma de Mallorca E07122, Spain
²Dep. Physical Materials Science, National Research Technological Univ. "MISIS", Moscow 119049, Russia
8. “Shape Memory Response and Magnetic Properties in the NiCoMnAl Polycrystalline Alloy”
W. Ito¹, B. Basaran², R.Y. Umetsu³, I. Karaman⁴, R. Kainuma¹, and K. Ishida¹
¹Department of Materials Science, Graduate School of Engineering, Tohoku University, 6-6-02 Aoba-yama, Sendai 980-8579, Japan
²Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843, USA
³Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, 2-1-1 Katahira, Sendai 980-8577, Japan

9. “Thermo-mechanical Model for NiTi Shape Memory Wires”
M. Frost¹, P. Sedlák¹, P. Sittner²
¹Institute of Thermomechanics, Academy of Sciences of the Czech Republic, Dolejškova 5, 18200 Prague, Czech Republic
²Institute of Physics, Academy of Sciences of the Czech Republic, Na Slovance 2, 18221 Prague, Czech Republic

Irmak Sargin¹, Benat Kockar², Tarık Aydogmus³, İbrahim Karaman⁴, Sakir Bor¹
¹Middle East Technical University, Metallurgical and Material Engineering Department, 06531, Ankara, Turkey.
²Hacettepe University, Mechanical Engineering Department, 06800, Ankara, Turkey.
³Department of Mechanical Engineering, Texas A&M University, MS 3123, College Station, TX 77843, USA

11. “Room Temperature Instabilities of Ti-based Shape Memory Alloys”
Ji Ma, I. Karaman
Department of Mechanical Engineering, Texas A&M University, MS 3123, College Station, TX 77843, USA

12. “Deformation Energy of NiTi Shape Memory Wires”
M. Akhlaghi, R. Mahmudi, M. Nili Ahmadabadi
School of Metallurgy and Materials Engineering, Tehran University, PO Box 11155-4563, Tehran, Iran

13. “Multi-scale Precipitation Effects in Ni-Rich NiTi Shape Memory Alloys”
E. Akin¹, K.C. Atli¹, I. Karaman¹,², Y.I. Chumlyakov³
¹Department of Mechanical Engineering, Texas A&M University, MS 3123, College Station, TX 77843, USA
²Materials Science and Engineering Interdisciplinary Graduate Program, Texas A&M University, College Station, TX 77843, USA
³Siberian Physical Technical Institute, Novosobornaya sq. 1, Tomsk, 634050, Russia

14. “Martensitic Transformation Characteristics of CoNiGa High Temperature Shape Memory Alloys”
E. Dogan¹, I. Karaman¹, Z.P. Luo², Y.I. Chumlyakov³
¹Department of Mechanical Engineering, Texas A&M University, MS 3123, College Station, TX 77843, USA
²Microscopy and Imaging Center, Texas A&M University, MS 2257, College Station, TX 77843, USA
³Siberian Physical Technical Institute, Novosobornaya sq. 1, Tomsk, 634050, Russia

15. “SMA Properties for Damping in Civil Engineering (Earthquake and Stayed Cables Mitigation)”
Vicenç Torra¹, Carlota Auguet¹, Antonio Isalgue¹, Francisco Carlos Lovey², Jorge Luis Pelegrina²
¹CIRG-DF-ETSECCPB, Polytexnic University of Catalonia, CAMPUS NORD B4-B5, E-08034 Barcelona, Catalonia, Spain
²Centro Atómico de Bariloche and Instituto Balseiro, 8400 S.C. de Bariloche, R.N., Argentina

16. “Calculation of Actuation Time of a Fast Heated Shape Memory Alloy Wire Drive”
N.A. Volkova, A.E. Volkov
Saint-Petersburg State University, Mathematical and Mechanical Faculty, NIIMM, pr. Universitetsky, 28, Stary Petergof, 198504 Saint-Petersburg, Russia
17. “Magneto-Thermo-Mechanical Characterization of Meta-Magnetic Shape Memory Alloys”
1Materials Science and Engineering Interdisciplinary Graduate Program, Texas A&M University, College Station, TX 77843, USA
2Department of Mechanical Engineering, Texas A&M University, MS 3123, College Station, TX 77843, USA
3Department of Materials Science, Graduate School of Engineering, Tohoku University, 6-6-02 Aoba-yama, Sendai 980-8577, Japan
4Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, 2-1-1 Katahira, Sendai 980-8577, Japan
3Department of Mechanical Engineering, University of Kentucky, Lexington, KY 40506-0503
6Siberian Physical Technical Institute, Novosobornaya sq. 1, Tomsk, 634050, Russia

Richard B. Griffin, Hanan Farhat
1Program Chair, Department of Mechanical Engineering, Texas A&M University at Qatar, Doha, Qatar
2Graduate Student, University of Saskatchewan

19. “Size Effect on the Phase Transformation of SMA Nanowires”
Francis Phillips, Fang Dong, Hongxing Zheng, Dimitris Lagoudas
1Materials Science and Engineering Interdisciplinary Graduate Program, Texas A&M University, College Station, TX 77843, USA
2Department of Aerospace Engineering, Texas A&M University, College Station, TX 77843, USA

S. Diliwal, R.F. Hamilton, H. Sehitoglu, H.J. Maier, Y. Chumlyakov
1Department of Mechanical Science and Engineering, University of Illinois, Champaign, IL 61821, USA
2Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16802-6812, USA
3University of Paderborn, Lehrstuhl f. Werkstoffkunde, D-33095 Paderborn, Germany
4Physics of Plasticity and Strength of Materials Laboratory, Siberian Physical and Technical Institute, 634050 Tomsk, Russia
## Technical Program

<table>
<thead>
<tr>
<th>Session 3-Part 1</th>
<th>8:45 - 10:20</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Session Chairs</strong></td>
<td>Sebastian Fähler, Tahir Cagin</td>
</tr>
</tbody>
</table>

**8:00 – 8:45**  
Breakfast (Main Campus Cafeteria)

**8:45 – 9:10**  
**“The NiMn-based Metamagnetic Shape Memory Alloys”**  
R. Kainuma¹, W. Ito¹, M. Nagasako¹, R. Y. Umetsu¹, T. Kanomata², and K. Ishida³  
¹Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, Sendai 980-8577, Japan  
²Faculty of Engineering, Tohoku Gakuin University, Tagajo 985-8537, Japan  
³Department of Materials Science, Graduate School of Engineering, Tohoku University, Sendai 980-8579, Japan

**9:10 – 9:30**  
**“Isothermal Characteristics of the Magnetostructural Transition in Metamagnetic Shape Memory Alloys”**  
S. Kustov¹, I. Golovin², M.L. Corró¹, E. Cesari¹, D. Salas¹, J. I. Pérez-Landazábal³, V. Recarte³  
¹Dept. de Física, Univ. Illes Balears, Cra. de Valldemossa, km 7.5, 07122 Palma de Mallorca, Spain  
²Dept. of Physical Metallurgy, National Technological Univ., Moscow Inst. of Steel and Alloys, Moscow 119049, Russia  
³Depto. de Física, Univ. Pública de Navarra, Campus de Arrosadía, 31006 Pamplona, Spain

**9:30 – 9:50**  
**“Magnetic Field-Induced Large Strain in Alloys and Ceramics Exhibiting Martensitic Transformations”**  
Tomoyuki Kakeshita, Tomoyuki Terai and Takashi Fukuda  
Department of Materials Science and Engineering, Graduate School of Engineering, Osaka University, 2-1, Yamada-oka, Suita Osaka, 565-0871, Japan

**9:50 – 10:10**  
**“The Consequences of Antiferromagnetism on Magnetic Shape Memory and Magnetocaloric Effects in Martensitic Heuslers”**  
M. Acet¹, S. Aksoy¹, A. Dannenberg¹, M. E. Gruner¹, P. Entel¹, L. Mañosa³, and A. Planes³  
¹Physics Department, Duisburg-Essen University, 47048 Duisburg, Germany  
³Departament d’Estructura i Constituents de la Matèria, Facultat de Física, Universitat de Barcelona, Diagonal 647, E-08028 Barcelona, Catalonia, Spain

**10:10 – 10:20**  
Discussion of the Papers in Session 3–Part 1

**10:20 – 10:35**  
**Coffee Break**

**10:35 – 10:55**  
**“Austenite Arrest in Ni-Mn based Shape Memory Alloys”**  
S. Aksoy¹, M. Acet¹, L. Manosa³, A. Planes³, and E. F. Wassermann³  
¹Experimentalphysik, Universität Duisburg-Essen, D-47048, Duisberg, Germany  
³Departament ECM, Universitat de Barcelona, E-08028 Barcelona, Catalonia, Spain

**10:55 – 11:20**  
**“First-Principles Description of Magnetic Shape Memory and Magnetocaloric Effects in Martensitic Heuslers”**  
P. Entel, A. Dannenberg, M. Siewert, M. E. Gruner, and M. Acet  
Faculty of Physics, University of Duisburg-Essen, 47048 Duisburg, Germany

**11:20 – 11:40**  
**“Anisotropic Elastic Properties and Magnetism in Ni-Mn-In based Alloys”**  
Tahir Cagin  
Department of Chemical Engineering, Texas A&M University, College Station, TX, U.S.A  
Materials Science & Engineering Graduate Program, Texas A&M University, College Station, TX, U.S.A
Technical Program

11:40 – 12:00
“Conventional and Inverse Magnetocaloric Effect in Heusler Ni50Mn34In16 Shape Memory Alloy: Monte Carlo Study”
V.D. Buchelnikov¹, V.V. Sokolovskiy¹, S.V. Taskaev¹, P. Entel²
¹Chelyabinsk State University, 454001 Chelyabinsk, Russia
²University of Duisburg-Essen, 47048 Duisburg, Germany

12:00 – 12:20
“Ab Initio Investigation and Thermodynamic Modeling of Co-Ni-Ga and Co-Ni-Al Shape Memory Alloys”
Raymundo Arroyave, Arpita Chari, Avinash Chivukula, Anchalee Junkaew
Department of Mechanical Engineering, Texas A&M University, TX, USA, 77843-3123

12:20 – 12:30
Discussion of the Papers in Session3-Part2

12:30 – 13:50 Lunch (Koc University Faculty Club)

13:50 – 14:10
“Superelastic Shape Memory Thin Films”
Eckhard Quandt, Christiane Zamponi, Rodrigo Lima de Miranda

14:10 – 14:30 “Solid State Diffusion Synthesis of NiTi”
Yinong Liu, Hong Yang, Jamaluddin Laeng, Hanim Mohd Zaki
Laboratory for Functional Materials, School of Mechanical Engineering, The University of Western Australia, 35 Stirling Highway, Crawley, WA6009, Australia

14:30 – 14:50
“Microstructure Formation and Hysteresis in Shape Memory Alloys”
O. Kastner¹, G.J. Ackland² and Gunther Eggeler¹
¹Institute for Materials, Ruhr-University Bochum, Germany
²School of Physics, University of Edinburgh, UK

14:50-15:10
“The Effect of Crystallization on the Microstructure and Phase Transformations of NiTi Shape Memory Thin Films”
Ainissa G. Ramirez
Department of Mechanical Engineering, Yale University, New Haven, CT 06520, USA

15:10 – 15:25
General Discussion of the Papers in Session4-Part1

16:30-18:30
Boat Tour of Boğaziçi (Starts at Sarýyer Port)

18:30-21:00
Workshop Banquet in Adile Sultan Palace

21:00-22:00
Evening Boat Tour of Boğaziçi and Return to Sarýyer
Technical Program

WEDNESDAY, June 23

Session5-Part1  8:45 - 10:45
Session Chairs  Hans Maier
               Mehmet Acet

8:00 – 8:45  Breakfast (Main Campus Cafeteria)

8:45 – 9:15
“Ni-free Ti-base Shape Memory Alloys”
Shuichi Miyazaki and Hee Young Kim
Institute of Materials Science, University of Tsukuba,
Tsukuba, Ibaraki 305-8573, Japan

9:15 – 9:35
“Thermoelastic Martensitic Transformation in High-
Strength Single Crystals”
Y. I. Chumlyakov1, I.V. Kireeva1, E. Y. Panchenko1, I.
Karaman2, H.J. Maier3, E.Cesari4
1Siberian Physical Technical Institute,
Novosobornaya sq. 1, Tomsk, 634050, Russia
2Department of Mechanical Engineering, Texas A&M
University, College Station, TX 77843, USA
3Lehrstuhl für Werkstoffkunde, University
Paderborn, 33095, Paderborn, Germany
4Department de Física, Universitat de les Illes Balears,
E-07122 Palma de Mallorca, Spain

9:35 – 9:55
“Superelasticity and Two-Way Shape Memory
Effect in Ni-Fe-Ga-Co Single Crystals”
J. Pons, F. Masdeu, E. Cesari
Dept. de Física, Univ. de les Illes Balears, Crta. de
Valldemossa km 7.5, E-07122 Palma de Mallorca,
Spain

9:55 – 10:15
“Superelastic Tensile Behavior of Ni-Mn-Ga Alloys”
V.A. Chernenko1,2, E. Villa3, S. Besseghini3,
J.M.Barandiaran1, J. Feuchtwanger1
1Universidad del País Vasco, Dpto. Electricidad y
Electronica, P.O. Box 644, E-48080 Bilbao, Spain
2Ikerbasque, Basque Foundation for Science, 48011,
Bilbao, Spain
3CNR-ILEI, C.Promessi Sposi, 29, Lecco 23900, Italy

10:15 – 10:35
“Huge Superelasticity and Magnetic Properties in
Fe-Ni-Co-Al based Shape Memory Alloys”
Y. Tanaka, R. Kainuma, Y. Sutou, T. Omori and K.
Ishida
Department of Materials Science, Graduate School
of Engineering, Tohoku University, 6-6-02 Aoba-
yama, Sendai 980-8579, Japan

10:35-10:45
Discussion of the Papers in Session5–Part 1

10:45 – 11:00  Coffee Break

Session5-Part2  11:00 - 12:30

11:00 – 11:20
“Multiple Length Scale Analysis of the Dual
Hysteresis Observed in NiMnGa Shape Memory
Alloys”
R.F. Hamilton1, H. Sehitoglu2, S. Dilibal3, K. Aslantas3,
H.J. Maier4
1Department of Engineering Science and Mechanics,
The Pennsylvania State University, 212 Earth-
Engineering Sciences Bldg., University Park, PA
16802-6812, USA
2Department of Mechanical Science and
Engineering, University of Illinois, 1206 West Green
Street, Champaign, IL 61821, USA
3Department of Mechanical Education, University of
Afyon Kocatepe, A.N.S Campus, Afyon 03200, Turkey
4University of Paderborn, Lehrstuhl f.
Werkstoffkunde, D-33095 Paderborn, Germany

11:20 – 11:40
“The Role of Interfaces in Bulk and Thin Film
Magnetic Shape Memory Alloys”
Sebastian Fähler
IFW Dresden, Helmholtzstrasse 20, 01069 Dresden,
Germany
Technical Program

11:40 – 12:00
"Magnetic Anisotropy and Magnetoelastic Coupling in Ni-Mn-Ga Magnetic Shape Memory Alloys"
O. Heczko1, H. Seiner2, P. Sedlák2, M. Landa2
1Institute of Physics, Na Slovance 2, CZ-182 21 Prague, Czech Republic
2Institute of Thermomechanics, Dolejškova 5, CZ-18200 Prague, Czech Republic

12:00 – 12:20
"Elastic Properties of Ni2MnGa from First-Principles Calculations"
S. Ozdemir-Kart1, T. Cagin2
1Department of Physics, Pamukkale University, Kınıklı Campus, 20017, Denizli, Turkey
2Department of Chemical Engineering, Texas A&M University, Texas, TX 77845-3122, USA

12:00 – 12:20
"Elastic Properties of Ni2MnGa from First-Principles Calculations"
S. Ozdemir-Kart1, T. Cagin2
1Department of Physics, Pamukkale University, Kınıklı Campus, 20017, Denizli, Turkey
2Department of Chemical Engineering, Texas A&M University, Texas, TX 77845-3122, USA

12:20-12:30
Discussion of the Papers in Session 5–Part 2

12:30 – 14:00 Lunch (Koc University Faculty Club)

14:00 – 14:20
"Fracture Mechanics of SMAs"
F. Furgiuele, C. Maletta
Department of Mechanical Engineering, University of Calabria, 87036 Arcavacata di Rende, Italy

14:20 – 14:45
"SMA in Damping for Earthquakes in Family Houses and in Stayed Cables for Bridges"
Vicenç Torra3, Carlota Auguet1, Antonio Isalgué1, Francisco Carlos Lovey2, Jorge Luis Pelegrina2, Patrick Terriault3, Lamine Dieng4
1CIRG-DFA-ETSECCPB, Polytechnic University of Catalonia, CAMPUS NORD B4-B5, E-08034 Barcelona, Catalonia, Spain
2Centro Atómico de Bariloche and Instituto Balseiro, 8400 S.C. de Bariloche, R.N., Argentina
3 Département de génie mécanique, école de technologie supérieure, 1100 Notre-Dame Ouest, H3C 1K3, Montréal, Québec, Canada
4 Laboratoire Central des Ponts et Chaussées Route de Bouaye BP 4129 44341 Bougenais Cedex, France

14:45 - 15:05
"Bulk and Porous Metastable Beta Ti-Nb-Zr(Ta) Alloys For Biomedical Applications"
V. Brailovski1, S. Prokoshkin2, M. Gauthier3, K. Inaekyan1, S. Dubinskiy1,2
1Ecole de Technologie Superieure, 1100, Notre-Dame Street West, Montreal (Quebec), H3C 1K3 Canada
2National University of Science and Technology "MISIS", Leninskiy prosp. 4, Moscow 119049, Russian Federation
3Industrial Materials Institute (IMI), National Research Council, Government of Canada, 75, de Mortagne, Boucherville (Quebec) J4B 6Y4 Canada

15:05 – 15:20
Discussion of the Papers in Session 6–Part 1

15:20 – 15:35 Coffee Break

15:35-15:55
"Correlation of the Defect Formation in Thin Polyelectrolyte Films with the Transformation Behavior of Polycrystalline NiTi Substrates"
J. Lackmann1, R. Regenspurger2, M. Maxisch2, G. Grundmeier2, H.J. Maier1
1Lehrstuhl für Werkstoffkunde (Materials Science),University of Paderborn, Pohlweg 47-49, 33098 Paderborn, Germany
2Technical and Macromolecular Chemistry, Department of Chemistry, Warburger Straße 100, University of Paderborn, D-33098 Paderborn, Germany
Technical Program

15:55 – 16:15
“Superelastic Response of NiTiHf-Based Shape Memory Alloys”
H. Karaca¹, G. Ded¹, S. Saghaian¹, B. Basaran¹, R. Noebe², H.J. Maier³, Y.I Chumlyakov⁴
¹Department of Mechanical Engineering, University of Kentucky, Lexington, KY 40506-0503
²NASA Glenn Research Center, M.S. 23-2, Cleveland, OH 44135, USA
³Lehrstuhl für Werkstoffkunde (Materials Science), University of Paderborn, Pohlweg 47-49, 33098 Paderborn, Germany
⁴Siberian Physical-Technical Institute, Tomsk, 634050, Russia

16:15 – 16:35
“Production and Mechanical Characterization of Ni-rich NiTi Porous Shape Memory Alloys”
Benat Kockar¹, Irmak Sargin², Tarık Aydogmus²
¹Hacettepe University, Mechanical Engineering Department, 06800, Ankara, Turkey.
²Middle East Technical University, Metallurgical and Material Engineering Department, 06531, Ankara, Turkey.

16:40 – 18:30 Panel Discussion and Coffee
8:00 – 9:00  Breakfast (Main Campus Cafeteria)

9:00 - 9:25  
“Shape Memory Thin Film Actuators”
Manfred Kohl
Karlsruhe Institute of Technology (KIT), IMT, Herrmann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

9:25 - 9:45  
“Modeling and Characterization of High Temperature Shape Memory Alloys”
D.C. Lagoudas\textsuperscript{1,2}, George Chatzigeorgiou\textsuperscript{3}, Yves Chemisky\textsuperscript{1}, Parikshith Kumar\textsuperscript{1}.
\textsuperscript{1}Department of Aerospace Engineering, Texas A&M University, College Station, TX 77843, USA
\textsuperscript{2}Materials Science and Engineering Interdisciplinary Graduate Program, Texas A&M University, College Station, TX 77843, USA

9:45 – 10:05  
“Energetics of Transformation and Twinning”
Huseyin Sehitoglu\textsuperscript{1}, T. Ezaz\textsuperscript{1}, S. Chowdury\textsuperscript{1}, H.J. Maier\textsuperscript{1,2}, Y. Chumlyakov\textsuperscript{1,3,4}
\textsuperscript{1}Department of Mechanical Science and Engineering, University of Illinois, 1206 West Green Street, Champaign, IL 61821, USA
\textsuperscript{2}University of Paderborn, Lehrstuhl Werkstoffkunde, D-33095 Paderborn, Germany
\textsuperscript{3}Siberian Physical Technical Institute, Novosobornaya sq. 1, Tomsk, 634050, Russia

10:05 – 10:25 “New Observations on Transformation Hysteresis, Room Temperature Instabilities, and Twinning in Shape Memory Alloys”
Ji Ma\textsuperscript{1}, Ibrahim Karaman\textsuperscript{1}, Benat Kockar\textsuperscript{2}, Haluk E. Karaca\textsuperscript{3}, Yuriy I. Chumlyakov\textsuperscript{4}, Hans J. Maier\textsuperscript{5}
\textsuperscript{1}Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843, USA
\textsuperscript{2}Hacettepe University, Mechanical Engineering Department, 06800, Ankara, Turkey
\textsuperscript{3}Department of Mechanical Engineering, University of Kentucky, Lexington, KY 40506-0503
\textsuperscript{4}Siberian Physical Technical Institute, Novosobornaya sq. 1, Tomsk, 634050, Russia
\textsuperscript{5}Lehrstuhl für Werkstoffkunde (Materials Science), University of Paderborn, Pohlweg 47-49, 33098 Paderborn, Germany

10:35 – 11:00  
Wrap-up Discussion

11:00-19:00  
Historical Tour of Istanbul
We give a brief introduction into the role of dislocations during martensitic transformations. We present some results on functional fatigue of NiTi actuators and identify the important crystallographic, chemical and microstructural parameters which govern functional fatigue [1]. We then show that the behaviour of a NiTi spring actuators during thermo mechanical cycling can only be rationalized in the light of a scenario where the density of dislocations increases during the subsequent forward and reverse martensitic transformations [2]. We show results from recent TEM studies which revealed one possible mechanism for an increase in dislocation density during a martensitic transformation. We discuss these results in the light of recent findings from other groups. We present some recent findings from MD simulations, which qualitatively support the experimental results. Areas in need of further work are finally highlighted.

**Abstracts**

**MONDAY, June 21**

**“Nanostructured Shape Memory Alloys”**

T. Waitz\(^1\), W. Pranger\(^2\), T. Antretter\(^3\), F.D. Fischer\(^3\), G. Steiner\(^1\), M. Peterlechner\(^1\)

\(^1\)Physics of Nanostructured Materials, Faculty of Physics, University of Vienna Boltzmanngasse 5, 1090 Vienna, Austria

\(^2\)Materials Center Leoben Forschung GmbH, Roseggerstraße 12, 8700 Leoben, Austria

\(^3\)Institute of Mechanics, Montanuniversität Leoben, Franz-Josef-Straße 18, 8700 Leoben, Austria

The phase stability of nanostructured martensitic materials can differ from that encountered in coarse-grained bulk materials. Crystal size at the nanoscale can strongly impact the self-accommodated morphology of the martensite. However, the shape-memory effect and superelastic properties of martensitic materials can persist even at the nanoscale. Nanocrystalline martensitic materials can be processed by severe plastic deformation to obtain tailored functional properties in combination with enhanced strength. With special emphasis on current challenges and future prospects, experimental achievements and theoretical approaches in the field of nanostructured shape memory alloys are outlined.

**MONDAY, June 21**

**“The Role of Symmetry, Intergranular Constraint and Texture Evolution on Elastic Strain Anisotropy in Polycrystalline Martensitic NiTi”**

R. Vaidyanathan\(^1\), S. Qiu\(^1\), O. Benafan\(^2\), B. Clausen\(^2\), S.A. Padula II\(^3\) and R.D. Noebe\(^3\)

\(^1\)Advanced Materials Processing and Analysis Center; Mechanical, Materials and Aerospace Engineering, University of Central Florida, Orlando 32816, USA

\(^2\)Los Alamos National Laboratory, Los Alamos 87545, USA

\(^3\)Materials and Structures Division, NASA Glenn Research Center, Cleveland 44135, USA

This work provides insight into the elastic response of B19' martensitic NiTi grains as they exist in bulk, polycrystalline aggregate form during monotonic loading. Emphasis is placed on capturing and quantifying the strain anisotropy which arises from the symmetry of monoclinic martensite (i.e., the thirteen elastic stiffness or compliance constants) and internal stresses resulting from intergranular constraints between individual variants and load re-distribution among variants as the texture evolves during detwinning and variant reorientation processes. The methodology adopted is both experimental and computational, and takes into account both tensile and compressive loading given the asymmetric response in the texture evolution. The experimental effort centers on using neutron diffraction during loading which allows for texture and atomic scale, volume-averaged mechanical characterization of several grains in bulk, polycrystalline aggregate form. The computational effort centers on a 30,000 grain self-consistent polycrystalline deformation model to predict the anisotropic elastic response of B19' NiTi based on recently reported elastic stiffness constants from \textit{ab initio} calculations \cite{1} and makes comparisons with the neutron diffraction experiments. The modeling effort additionally assesses the role of grain-scale, intergranular stresses in the consolidated polycrystalline bulk response. As done previously for the case of thermal strains \cite{2}, connections are also made between the assessed elastic properties of martensitic NiTi single crystals (i.e., the single crystal stiffness tensor) and the overall macroscopic response in bulk polycrystalline form. The aforementioned results are also used to follow and evaluate the internal strain evolution in NiTi during a typical shape-setting process and thermomechanical cycling.


\[2\] S. Qiu \textit{et al.}, Appl. Phys. Lett. 95, 141906 (2009)
“Some Factors Affecting the Transformation Characteristics of Shape Memory Alloys”
Yong Liu and Mehrdad Zarinejad
School of Mechanical and Aerospace Engineering, Nanyang Technological University, Nanyang Avenue, Singapore 639798

Transformation characteristics are among the most important properties of shape memory alloys. Depending on applications, the required response temperatures and transformation hysteresis vary significantly. To date, great efforts have been made to develop SMAs having a wide range of transformation temperatures. However, most of the activities are based on empirical knowledge with unsatisfactory guidance from scientific principles. When being used for repeated actuation purposes (for example as actuation mechanisms in MEMS, flapping wing and morphing wing of aerial vehicles, robotics, etc.) a small transformation hysteresis is required for higher actuation frequency and lower power consumption. On the other hand, some applications require very large transformation hysteresis in order to maintain a stable austenite phase within a large temperature range for sustaining the predefined shape (for example in deployable space structures, pipe joining, etc).

This presentation will highlight some of the recent results we have obtained on revealing the factors controlling the transformation characteristics of shape memory alloys including both transformation temperatures and transformation hysteresis. Particularly, it is found that the transformation temperature of SMAs has an overall dependence on the number and concentration of valence electrons within a temperature range between -200°C and 1100°C. The discovered relation may provide an effective guidance for alloy design. In addition, some factors that affect the transformation hysteresis will also be presented and discussed.

“Morphology and Crystallography of Self-accommodated B19’ Martensite in Ti-Ni Shape Memory Alloys”
Minoru Nishida¹, Tomohiro Nishiura¹, Tomonari Inamura²
¹Department of Engineering Sciences for Electronics and Materials, Faculty of Engineering Science, Kyushu University, Kasuga, Fukuoka, 816-8580
²Precision and Intelligence Laboratory, Tokyo Institute of Technology, 4259 Nagatsuta, Midori-ku, Yokohama 226-8503, Japan

Ti-Ni alloys of the near-equatomic composition are technologically important materials with their superior shape memory and superelastic properties associated with thermoelastic martensitic transformation. The microstructure of the martensite in shape memory alloys is characterized by the combination of multiple habit plane variants (HPVs) for the reduction of elastic strain energy upon transformation, which is called self-accommodation. There are two pioneering works on the self-accommodation of B19’ martensite of Ti-Ni alloy performed by Miyazaki et al [1] and Madangopal [2]. However, there is large discrepancy between those two results. In the present study, the self-accommodation morphology of the B19’ martensite is systematically investigated by optical and transmission electron microscopy observations. There are twelve pairs of the minimum units consisting of two habit plane variants with V-shaped morphology connected to a {11-1}B2 type I variant accommodation twin. It is found that the ideal self-accommodation morphology consists of three V-shaped units, i.e., a total of six habit plane variants, clustered around one of the <111>B2 poles. We will discuss on the reason why the triangular morphology consisting of three habit plane variants is frequently observed. High resolution electron microscopy observations of the interface between HPVs will be also presented. The obtained results of the crystallography at various interface structures well agree with the predictions from the phenomenological theory of martensite crystallography.

Abstracts

**MONDAY, June 21**

**13:50 - 14:15**


E. Patoor¹, Y. Chemisky², A. Duval³, B. Piotrowski³, T. Ben Zineb³

¹LPMM, Arts et Métiers Paris Tech Arts et Métiers ParisTech, 4, rue Augustin Fresnel 57078 Metz, France
²Texas A & M University, 733 H. R. Bright Building, College Station, TX 77843-3141, USA
³LEMTA, Nancy University, CNRS, France Nancy University, 2 rue Jean Lamour, 54500 Vandoeuvre-les-Nancy, France

This presentation deals with different applications of the macroscopic model we have developed to describe the behavior of Shape Memory Alloys (SMA). This phenomenological 3D-model is based on microstructural considerations and developed into the framework of thermodynamics of irreversible processes. The material behavior is described by three internal variables: the martensite volume fraction, the mean transformation strain and the mean strain due to the inelastic accommodation of twins inside the martensite phase. The third internal variable is introduced to account the strain mechanism which takes place inside self-accommodated martensite in NiTi SMAs. The Gibbs free energy expression is modified to better describe the complex behavior that occurs at low stress level in SMAs. This formulation allows the simulation of different thermomechanical responses like superelasticity, shape memory effect and constrain recovery. Moreover, some key characteristics: tension-compression asymmetry and inner loops inside the major hysteresis loop are taken into account. Numerical simulations for various thermomechanical loading paths are presented to illustrate the present model capability to capture the complex behavior of SMAs. This model is implemented into the finite element software ABAQUS and three different kinds of applications will be addressed in this presentation. The first application is related to structure analysis and the numerical tool such developed will be applied for biomedical applications design. The second application considers the influence of elastic Ni₄Ti₃ precipitates on the behavior of an annealed Ni-rich alloy. A unit cell finite element analysis is performed with elastic inclusions embedded into a SMA matrix. In the third application a Mori-Tanaka homogenization scheme is developed to describe the influence of elasto-plastic Nb inclusions on the effective behavior of NiTiNb SMAs.

**MONDAY, June 21**

**14:15 - 14:35**

“**Constitutive Equations for Martensitic Reorientation and Detwinning in Shape-Memory Alloys**”

Prakash Thamburaja and Pan Haining

Department of Mechanical Engineering, National University of Singapore, Singapore 117576

In this presentation, we present a recently-developed crystal-mechanics-based constitutive model to describe the martensitic reorientation and lattice correspondence variant detwinning in single crystal shape-memory alloys. The constitutive model has been derived in a thermodynamically-consistent manner and implemented into the ABAQUS finite-element program by writing a user-material subroutine. We also describe a set of physical experiments conducted on a polycrystalline rod shape-memory alloy initially in the martensitic state under a variety of stress-states e.g. simple tension, simple compression, tension-torsion-type loadings. In this talk, we show that the constitutive model and its numerical implementation are able to accurately describe the stress-strain responses of the aforementioned physical experiments. In particular, we show that our constitutive model is able to reproduce the experimentally-observed tension-compression asymmetry exhibited by initially-martensitic polycrystalline rod shape-memory alloy.
Experimental and numerical analysis of the effect of stress–strain heterogeneities (due to elastic anisotropy, grain orientations and interactions) on martensitic transformation are investigated for a Cu-Based SMA multicrystal. The shape and crystallographic orientation of each grain are measured successively by optical microscopy and Electron Back Scattered Diffraction (EBSD) technique. During a tensile loading at room temperature, the displacement field of the free surface is measured by Digital Image Correlation (DIC) with the software CORRELI-Q4. The strain field is then derived numerically. A finite element model is designed. The shape of each grain is defined as a sub-domain and meshed by three dimensional continuum elements. A behavior law, describing the thermomechanical response of a SMA single crystal, is adopted and implemented into the Abaqus finite element code. It is based on a micromechanical approach and takes into account the various possible active martensitic variants. The study shows that the experimental and numerical results are in good agreement. Moreover, the stress state in grains is disturbed by the neighboring grains and this disturbance has a strong influence on the martensite variant activation. Finally, the study shows that the martensitic transformation mainly occurs in localized bands involving the well crystallographic oriented grains with respect to the loading direction.


A microstructural model of deformation of shape memory alloys accounting for the martensitic phase transformation and microplastic deformation is supplemented with equations describing the accumulation of deformation defects of two types, one responsible for the isotropic hardening and the other for the translational hardening of the material. It is assumed that the translational hardening is connected with the formation of defects producing long-range stress fields and the density of these defects can increase and decrease during the deformation, so that they may be referred to as defects reversible by deformation. The isotropic hardening is due to the accumulation of scattered defects, which are irreversible by deformation, produce but short-range stresses and hinder the movement of dislocations. The calculations have shown that an account of the two types of hardening allows obtaining a more accurate description of the recoverable and irrecoverable strain of a TiNi specimen experiencing multiple phase transformations under cyclic variation of stress or temperature.
Abstracts

**MONDAY, June 21**

15:40 - 16:00

"Determination of Phase Transformation Surfaces around the Crack Tip at the Interface of a Bimaterial made of a Shape Memory Alloy and an Elastic Medium"

Mohamed Rachid Laydi, Christian Lexcellent

FEMTO-ST, Département de Mécanique Appliquée, 24 rue de l'Epitaphe, 25000 Besançon, France

The aim is to extend the investigation about the phase transformation surfaces around the crack tip of a bimaterial made of a shape memory alloy (SMA) and an elastic medium. With a SMA as equivalent Huber-Von Mises stress model, Freed, Banks-Sill (2008) determine these yield surfaces. In the present paper, the obvious asymmetry between tension and compression is integrated for the surfaces prediction. Its effect is weak concerning the shape and the width of these surfaces if the elastic constants of the two materials are not very different. This corroborates the small change of the "local phase angle" values with the intensity of the asymmetry.


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®MONDAY, June 21®

16:00 - 16:20

"Analysis of the Deformation Stage Prior the Superelastic Localised Tensile Stress Plateau of a Ti-50.6at%Ni"

D. Favier1, H. Louche1,2, Y. Liu3, L. Orgéas1, P. Schlosser1,2

1 Université de Grenoble/CNRS, 35R, BP 53, 38041 Grenoble Cedex 09, France
2 Université de Savoie, SYMME, BP 80439, 74944 Annecy le Vieux Cedex, France
3 The University of Western Australia. School of Mechanical Engineering, Crawley, WA 6009, Australia

Uniaxial superelastic tensile tests on polycrystalline NiTi samples exhibit localized Lüders-like deformation during loading and unloading over two stress plateaus. The upper stress plateau is preceded by a quasi-linear initial deformation. Understanding of the deformation mechanisms during this stage is of fundamental and practical importance, e.g., to determine the true value of macroscopic Young's modulus or engineering stiffness, both of which being important design parameters for the application of the alloys. The reported values for macroscopic Young's modulus determined form mechanical testing vary widely in the literature from 40 to 90 GPa. Several authors have presented experimental evidences revealing the occurrence of other deformation mechanisms such as phase transformation during this stage.

The aim of this study is to further investigate deformation mechanisms within this stage by using infrared measurements and heat source estimation during tensile tests under different thermomechanical loading conditions on polycrystalline Ti-50.6at.% Ni plates presenting no R-phase. This paper presents the special experimental set-up for this measurement and several tensile tests conducted to just before the onset of the stress plateau. Estimation of macroscopic Young's modulus is discussed, then heat source estimated from temperature variation along the sample gauge length is analysed. Based on these analyses, latent heat of the stress-induced A→M phase transformation and the fraction of martensite formed during this initial stage of quasi-linear tensile deformation are determined.
“Role of Loading Time in the Deformation Patterns of Shape Memory Alloys”
Qingping Sun and Yongjun He
Department of Mechanical Engineering, The Hong Kong University of Science and Technology, Hong Kong, China

In this talk we present our recent modelling and experiment on the tensile stress-induced phase transition process in NiTi shape memory alloys, focusing on the role of loading time scale and the thermo-mechanical two-field coupling in the deformation domain patterns. We first report the effects of loading time or stretching rate on the domain patterns observed in NiTi strips in the strain rate range of $10^{-4}/s$ ~ $10^{-1}/s$. It was found that the nominal stress-strain curve of the specimen changed from near-isothermal plateau-type with distinct stress-drops in the low strain rate region to the near-adiabatic smooth hardening-type in the high strain rate region. The corresponding deformation mode changed from the localized-propagation mode with a few parallelepiped martensite domain patterns to the near-homogeneous multiple-nucleation mode with fine alternating austenite-martensite stripes. The number of the macroscopic domains (domain spacing) of the specimen increased (decreased) with the applied stretching rate in a power-law form, i.e., the higher the loading rate, the finer the deformation pattern. The analysis showed that such observed power-law dependency is originated from the coupling between the material’s nonlinear property (nucleation and growth of domains) and the transfer of latent heat. The important roles of heat transfer dynamics and loading time in imposing the emerging length scale in the deformation pattern of the material is demonstrated. A simple scaling law for the rate dependent domain spacing is developed which agree quantitatively well with the experiments.

“Non-Monotonic Two-Way Shape Memory in Titanium Nickelide”
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Two-way shape memory in TiNi shape memory alloy after high strain rate loading was investigated. The loading was carried out applying tension in austenitic state. It was revealed, that the pattern of strain-temperature dependency was non-monotonic both for monotonic increase and for monotonic decrease of the temperature. By nature this effect is different from the so called “all-round shape memory effect” [1]. It was found that the reversible non-monotonic behavior is a mutual effect of austenitic and martensitic types of two-way shape memory similar to reversible two-way shape memory [2].

Abstracts

“The Effect of Irradiation on Microstructure and Phase Transformation of Shape Memory Alloys”
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Irradiation causes significant changes in the microstructure of metallic materials due to the interaction of energetic particles with host atoms. The result of primary interactions is the creation of point defects. In turn, higher order defects such as defect clusters and voids are created due to the agglomeration of radiation induced point defects. Thus, mechanical properties of materials are strongly affected by irradiation. The most significant observation is the loss of ductility and strengthening upon irradiation. Another important effect of irradiation is on phase transformation. Phase segregation and nucleation of new phases or precipitates may be observed as a result of irradiation. It is highly desirable to assess the irradiation effect on material characteristics and performance due to these phenomena. Certain characteristics of martensitic transformations such as twin formation mechanism and critical temperatures are altered upon irradiation. Shape memory alloys which experience martensitic transformation have been widely employed as multifunctional materials in diverse applications. This study covers the issues observed and experienced in shape memory alloys due to irradiation. The main focus will be micro-structural features created upon irradiation and phase transformations in shape memory alloys. Type of irradiating particles as well as dose and temperature effects will be discussed.
1. “Effect of Time Scales on Hysteresis Damping in Superelastic NiTi Shape Memory Alloys”
Qingping Sun and Yongjun He
Department of Mechanical Engineering, The Hong Kong University of Science and Technology, Hong Kong, China

Recent experiments showed that the pseudoelastic hysteresis of NiTi shape memory alloys (SMA) varies non-monotonically with the external loading rate and the maximum hysteresis occurs at certain intermediate loading rate. Results of recent experiments under different heat convection conditions are reported in this presentation and a simple two-scale thermo-mechanical coupling model is developed to explain the observed rate-dependent hysteresis phenomenon. The important effects of temperature history, i.e., the effects of the released/absorbed heat of the phase transition and the heat transfer on the pseudoelastic hysteresis, have been demonstrated. A simple scaling law for the rate-dependent hysteresis is obtained and the theoretical predictions agree quantitatively well with the experiments.

2. “Morphing Laminar Wing with Flexible Extrados Powered by Shape Memory Alloy Actuators”
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An experimental morphing laminar wing was developed in the framework of the CRIAQ7.1 project (ETS, Polytechnique, IAR-NRC) to prove the feasibility of aircraft fuel consumption reduction through enhancement of the laminar flow regime over the wing extrados. The morphing wing prototype designed for subsonic cruise flight conditions (Mach 0.2…0.3; angle of attack -1…+2°) combines three principal subsystems: (1) flexible extrados, (2) rigid intrados and (3) an actuator group located inside the wing box. The morphing capability of the wing relies on controlled deformation of the wing extrados under action of two chord-wise spaced shape memory alloys (SMA) actuators. A coupled fluid-structure model of the morphing wing was used to evaluate its mechanical and aerodynamic performances in different flight conditions. Fulfilling the requirements imposed by the morphing wing application to the force-displacement characteristics of the SMA actuators, their geometry and assembly conditions were determined. A 0.5 m chord – 1 m span prototype of the morphing wing was tested in a subsonic wind tunnel using open and closed-loop control strategies. Infrared thermography measurements recorded an average 25% improvement of the laminar flow region over the upper wing surface due to extrados morphing. According to the wind-tunnel balance and wake pressure data obtained under constant-lift conditions, extrados morphing allowed an average drag reduction of 18.5% for 8 flow cases covering the flow condition range of interest, thus confirming a significant potential of such a concept for greener aviation.

3. “Effect of Heat-Treatment on the Mechanical Behavior of Ni$_{24.5}$Ti$_{50.5}$Pd$_{25}$ Polycrystals at Elevated Temperatures”
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High-temperature shape memory alloys are an emerging topic in industry, especially in the aircraft and aerospace sectors. This paper presents the results of experiments designed to analyze the changes in the behavior of NiTiPd specimens tested prior to and after heat-treatment in order to understand the impact of heat treatment on this material. The tests undertaken were designed mainly to investigate functional fatigue. Substantial variations in material behavior, especially irrecoverable strains were found.

Data from different processing conditions were obtained in order to establish the mechanical behavior of crystals with different microstructural features. The first condition was hot extruded at 900 °C with a 7:1 area reduction, the second one was vacuum heat-treated for 1 hour at 900 °C and finally, the third was initially tested and then heat-treated at 900 °C. In the experiments the samples were heated and cooled at seven incremental stress levels. The first cycle was conducted at 50 MPa, in the
following the stresses were increased stepwise by 50 MPa up to a value of 350 MPa. Within each of these seven cycles, the temperature loop started at 100 ºC, was increased to 290 ºC and decreased to 100 ºC again. The obtained results show distinct differences as the specimen that was pre-tested and heat-treated showed a superior behavior characterized by the smallest irrecoverable strains.

In order to identify the differences in the functional fatigue behavior thorough microstructural investigations by means of electron optical microscopy were conducted. Electron backscatter diffraction (EBSD) was used to characterize the different microstructures on a large scale and transmission electron microscopy (TEM) was used to investigate small scale details of each condition. Especially TEM revealed distinct microstructural differences, e.g. the twinning activities in the different conditions are substantially different.

4. “Competing Mechanisms of Phase Transformation, Plasticity and Creep in High Temperature Shape Memory Alloys”
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Zr, Hf, Pd and Au ternary alloying additions to traditional NiTi shape memory alloys (SMAs) push the martensitic transformation temperatures above 100°C and create high temperature SMAs (HTSMAs). While this allows applications in the aerospace, automotive and oil drilling industries as high temperature actuators, their transformation temperature’s proximity to thermally activated mechanisms, such as creep and secondary phase precipitation, make them dimensionally unstable. Ni\textsubscript{20}Ti\textsubscript{50}Pd\textsubscript{30} exhibits transformation temperatures close to its creep regime and does not allow Ni-rich secondary phase precipitation. Combined with the volumetric difference between austenite and martensite, this makes it a perfect material to study only the oriented martensite, transformation induced plasticity and creep contributions to residual strain accumulation.

A specimen is initially thermally cycled at under no-load conditions, 0MPa, to observe the volumetric differences between austenite and martensite. The specimen is then thermally cycled to increasing upper-cycle temperatures under 200MPa to induce oriented martensite, transformation induced plasticity and creep strains. The specimen is then unloaded and cycled at 0MPa, again with increasing upper-cycle temperature, until the original no-load response is observed and stabilizes. It is believed the oriented martensite contributions are recovered leaving the plastic and creep contributions to residual strain. It is observed that the creep and plastic mechanisms can contribute greatly to the overall accumulated strains. This form of experiment will help create better HTSMA models that dissociate oriented martensite from transformation induced plasticity and creep. It also shows that upper-cycle temperature can have a great impact on an actuator’s dimensional instability and must be considered for design purposes.
5. “Improved Dimensional Stability and Cyclic Response of Ultrafine Grained NiTiPd Shape Memory Alloys”
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There is a growing demand for high-temperature shape memory alloys (HTSMA) as solid-state actuators in the aerospace, automotive, and power generation industries. Since conventional NiTi has transformation temperatures limiting its use well below 100°C, ternary additions have been successfully implemented to achieve increased transformation temperatures. Within this framework, NiTiPd alloys have attracted considerable attention as HTSMAs, since their transformation temperatures can reach as high as 500°C while they also exhibit significant strain recovery under both constrained and unconstrained conditions. However, as the transformation temperatures are increased, dislocation processes and thermally driven mechanisms become more dominant deteriorating the shape memory behavior and dimensional stability.

The objective of this study is to improve the dimensional stability of a Ti50.5Ni24.5Pd25 HTSMA by suppressing dislocation plasticity during phase transformation. Equal channel angular extrusion (ECAE) process was employed to increase the critical stress for dislocation slip of the material through grain size refinement and strain hardening. Accelerated “training” was also used as an alternative method to obtain improved dimensional stability. It involved thermally cycling the material at stresses above the anticipated application stress. It was shown through isobaric thermal cycling tests that both ECAE processed and “trained” materials displayed enhanced dimensional stability with smaller residual strains and enhanced thermal efficiency with narrower thermal hysteresis values. Improvements in the properties after ECAE processing were attributed to the strengthening of the material through grain refinement, which was backed up by electron microscopy results. The stress at which accelerated “training” took place dictated the shape memory characteristics, including the amount of two-way shape memory effect (TWSME), thermal hysteresis and recovered transformation strain.

6. “Anomaly of Critical Stress in Stress-Induced Transformation of NiCoMnIn Metamagnetic Shape Memory Alloy”
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Recently, the kinetic arrest phenomenon, in which martensitic transformation is interrupted at certain temperatures (noted as kinetic arrest temperature, \( T_{KA} \)) during field cooling and does not proceed with further cooling, has been reported in Ni45Co5Mn36.7In13.3[1, 2] and Ni50Mn34In16[3, 4] alloys. This phenomenon is thermodynamically explained by the disappearance of driving force for thermal transformation due to an abnormal decrease of the transformation entropy change (\( \Delta S \)) at temperatures below the \( T_{KA} \) brought about by the magnetic term in the Gibbs energy. If this explanation is correct, a similar anomaly caused by the abnormal temperature dependence in the \( \Delta S \) is also expected in the stress-induced transformation. In the present study, the critical stress in stress-induced transformation at several temperatures was determined and the \( \Delta S \) was evaluated.

Ni45Co5Mn36.1In11.9 alloy was prepared by induction melting under an argon atmosphere. Prolonged annealing of the ingot for homogenization and for large grains was conducted at 1173 K for 37 days in a vacuum. A single crystal specimen for compression test was cut out off from the as-quenched ingot with large grains by using a spark-cutting machine. The compression orientation in the single crystal specimen was determined by electron back-scattered diffraction. Compression tests were performed at several temperatures from 123 K to 298 K.
While this alloy showed no thermal martensitic transformation during cooling down to 4.2 K, the stress-induced martensite phase appeared at all the testing temperatures. While the equilibrium stress, which was estimated from the critical stresses for the forward and reverse transformations, decreases with decreasing temperature, its gradient to temperature gradually decreases and finally reaches almost zero at about 140 K. The transformation entropy change estimated from the stress-strain curves was in good agreement with those from the magnetization and the DSC measurements for Ni_{45}Co_{5}Mn_{50-x}In_{x} alloys.


7. “Anelasticity and Reversible Villary Effect in Ni-Mn-In-Co Metamagnetic Shape Memory Alloy”
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We study linear and non-linear anelasticity (strain amplitude-independent and strain amplitude dependent internal friction and strain amplitude dependent Young’s modulus defect) in a metamagnetic Ni-Mn-In-Co alloy over the temperature range 80-350 K, covering the martensitic transformation interval. Measurements are performed by means of a piezoelectric composite oscillator technique using longitudinal resonant oscillations of samples at a frequency of about 90 kHz for strain amplitudes from 10^{-7} to 10^{-4}. Acoustic measurements are accompanied by registering the reversible inverse magnetostriction (reversible Villary effect). Temperature spectra of anelasticity and reversible Villary effect are obtained under different values of longitudinal polarizing field up to 18 kA/m. In addition, experiments are performed at fixed temperatures under cyclic polarizing field.

We found that, contrary to non-magnetic and ferromagnetic shape memory alloys, in this metamagnetic alloy the anelasticity of the austenitic phase is substantially higher than in the martensitic state. We suggest that the origin of this unusual relationship between damping properties of different phases is in the high level of magnetomechanical damping of ferromagnetic austenite and its absence in non-magnetic martensite. Linear and non-linear components of damping in the austenitic phase demonstrate opposite dependence on polarizing field, suggesting that they are related to macroeddy and hysteretic components of magnetomechanical damping, respectively.

8. “Shape Memory Response and Magnetic Properties in the NiCoMnAl Polycrystalline Alloy”
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Recently, the shape memory (SM) effect due to magnetic field-induced reverse transformation, namely, metamagnetic shape memory effect, has been reported in the NiCoMnIn single crystalline and the NiCoMnSn polycrystalline alloys[1,2]. In these materials, excellent magneto-strain properties, such as the large output stress and strain and the rapid response, required for actuator materials are expected. However, the relatively high cost of NiCoMnIn alloys due to expensive In and the brittleness of both the NiCoMnIn and NiCoMnSn alloys in polycrystalline form are the major problem in practical applications. Very recently, we have reported that the magnetic field-induced reverse transformation is obtained also in Co-doped NiMnAl alloys[3]. In the present study, magnetic and SM properties of the polycrystalline NiCoMnAl alloys were investigated and the following results were obtained:
Poster Abstracts

(1) Magnetic properties of the parent phase drastically change from paramagnetic to ferromagnetic due to the addition of Co, while the magnetization of the martensite phase slightly decreases. In Ni$_{40}$Co$_{10}$Mn$_{33}$Al$_{17}$ alloy, a magnetic field-induced reverse transformation was confirmed at 345 and 350 K.

(2) The Ni$_{40}$Co$_{10}$Mn$_{33}$Al$_{17}$ specimen shows some ductility even in the polycrystalline form and the SM strain of about 3.6% was obtained in temperature change under a fixed stress of 200 MPa. The stress dependence of the transformation temperatures is expressed with linear relationships, the slopes of which almost match with the value of the Clausius-Clapeyron equation calculated using the experimental data in the entropy change and the transformation strain.

(3) An almost perfect pseudoelasticity (PE) was detected at 405 K during compressive straining up to 2.5%.

The NiCoMnAl metamagnetic SM alloys in polycrystalline form can provide a high ductility and an excellent SM and PE properties at relatively elevated temperatures.


9. “Thermo-mechanical Model for NiTi Shape Memory Wires”
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Optimal design of SMA applications requires detailed knowledge of material properties and modeling tool capable to capture thermomechaical and multiaxial loading modes (combination of heating, tension, torsion in case of wires). This sets a new area for experimentation and computational modelling. Macroscopic models are usually developed with the aim to effectively simulate response of a polycrystalline SMA material element with respect to computational robustness, stability, adaptability and reasonable computational time. However, reliable understanding of involved processes and knowledge of internal microstructure are crucial for development of such models. For instance, the nonproportional thermomechanical loading seems to be one of the most challenging issues for SMA modelling at present.

Based on experimental research focusing behaviour of NiTi wires and motivated by the need to simulate NiTi wires structures as textiles, uniaxial and tension-torsion SMA material models were developed subsequently. They are parameterised by realistic physically based material parameters and they capture superelasticity, reorientation/twinning in martensite and one-way shape memory effect. A new 3-D model, which tries to cope with nonproportional loading, is also suggested. The model involves nonhomogenous redistribution of stress between austenite and martensite in case of nonproportional loading. The models already proved their ability to successfully simulate NiTi wire applications under thermal and mechanical loading – numerical results for knitted self-expanding stent, shape memory fastener hook, shape memory helical spring are presented – as well as to explain the puzzling behaviour of NiTi wire under combined tension-torsion loading.
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The purpose of this study is to investigate the effect of stress-assisted aging on stress induced martensitic transformation of hot-rolled Ni-rich NiTi alloy. The relation between the multistep transformation in aged Ni-rich NiTi and superelasticity behavior has been questioned and it is determined that the stress level during aging is found to be an important parameter on the superelastic behavior of this alloy.

Hot rolled 50.7at% Ni-Ti alloys are aged under 0MPa, 20 MPa, 100 MPa, and 200 MPa at 400 °C for 324 ks. Phase transformation temperatures are determined by differential scanning calorimetry in the temperature range from -150 to +100 °C and the superelasticity experiments are conducted by loading and unloading the samples to 3.5% and 0% constant strain levels respectively. As a result, the critical stress for transformation is decreased following to aging treatments. The critical stress level of the sample aged under 20 MPa is slightly different than that of the unaged and free aged samples. However, the effect of the applied stress becomes pronounced when it is increased to 100 MPa during aging. The degree of change in critical stress level is also found to be decreasing again between 100 MPa and 200 MPa. The multistep transformation has been observed in freely aged and aged under 20 MPa samples, whereas it is single step and two-step for samples aged under 100 MPa and 200 MPa, respectively.

11. “Room Temperature Instabilities of Ti-based Shape Memory Alloys”
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Superelastic cycling of shape memory alloys (SMAs) usually results in a gradual reduction in critical stress to induce martensitic transformation (σ_{SM}) and stress hysteresis (Δσ), and an increase in irrecoverable strain (ε_{irr}). These changes are traditionally considered to be related to plasticity and therefore permanent. However, we have found this not to be the case in the titanium-niobium and nickel-titanium SMAs. In both alloys, aging at room temperature following superelastic cycling produced gradual, but significant recovery in both σ_{SM} and Δσ, implying that room temperature aging is able to erase changes to the superelastic behavior accumulated during cycling. Furthermore during cycling of the Ti-Nb alloy, growth in cumulative ε_{irr} abated after several hundred cycles, and was surprisingly followed by a slow depletion of the accumulated ε_{irr} with increasing cycle numbers, sometimes resulting in a complete disappearance of ε_{irr} after 1000 cycles. This behavior was not observed in the Ni-Ti alloy. Both room temperature aging and cyclic recovery phenomena are influenced by microstructure of the specimen, and are believed to be caused by inherently diffusion-based mechanisms related to evolution of defect structure during the superelastic cycling process. However, it does not appear that a single mechanism is responsible for both behaviors.

12. “Deformation Energy of NiTi Shape Memory Wires”
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Deformation energy of NiTi wire has been studied by the Multiple Tensile Testing (MTT) method. In traditional materials, the total energy required to tear specimens is assumed to be the sum of elastic, uniform plastic, and post-uniform or tearing energy components. For the shape memory alloys, however, this classification is not valid due to their unusual superelastic and shape memory characteristics. Thus, the analysis of their deformation energy should consider the extra deformation regimes present in the tensile curves of these materials. Tearing energy was calculated by plotting the total energy divided by the specimen cross-sectional area against the gage length of the specimens. The slope of the obtained straight line, demonstrates the summation of the elastic and plastic energy per unit volume and its intercept gives the value of tearing energy. Austenite (B2 phase) and martensite (R phase) wires were produced through different aging treatments carried out on the same as-received NiTi material. The tensile tests were carried out at the room temperature at the initial strain rate of 10^{-4} s^{-1}. In order to separate elastic and plastic energies in the austenite wire, the total elastic energy was plotted against the volume of specimens.
and the slope of the curve, elastic energy per unit volume, was approximated as the superelastic energy. The same procedure was adopted for the martensite wire in order to obtain the shape memory energy. It was found that the tearing energy per unit area and the plastic energy per unit volume for the martensite wire were considerably higher than those for the austenite wire. This causes a marked enhancement in the total deformation energy of the martensite wire, as compared to the austenite wire.

13. “Effect of Aging Heat Treatments on Ni$_{32}$Ti$_{48}$ Shape Memory Alloy”
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Ni-rich NiTi shape memory alloys (SMAs) are capable of attaining a wide range of transformation temperatures depending on the heat treatment conditions and superior thermo-mechanical cycling stability, which is desired for repeated solid-state actuation. High Ni-content Ni-rich SMAs have very low transformation temperatures in solutionized condition due to the high Ni-content of the matrix. Slow cooling (furnace-cooling) after solution heat treatment and additional aging heat treatments result in the formation of Ni-rich precipitates such as Ni$_4$Ti$_3$, Ni$_3$Ti$_2$ and Ni$_3$Ti and increase transformation temperatures above ambient by depleting excess Ni from the matrix. However, the precipitates do not undergo a martensitic phase transformation; they decrease the transformation strain by reducing the volume fraction of the material capable of transforming. In addition, a recent preliminary work shows that Ni$_3$Ti precipitates govern fatigue failure.

The objectives of the present study are to eliminate Ni$_3$Ti while keeping Ni$_4$Ti$_3$ type precipitates, which are responsible for the dimensional stability; to select single variant Ni$_4$Ti$_3$ precipitates through constrained aging in order to obtain enhanced dimensional stability and two-way shape memory effect (TWSME) which is costly and time consuming to achieve through conventional training methods. Based on these objectives, the effect of aging heat treatment on transformation temperatures, microstructure and shape memory behavior are investigated for a Ni$_{32}$Ti$_{48}$ SMA using differential scanning calorimetry (DSC), optical microscopy, scanning electron microscopy (SEM) and thermo-mechanical testing including isobaric heating-cooling experiments under various stress levels. It was observed that solutionizing at 900 °C for 24 hours eliminated Ni$_3$Ti precipitates but additional aging heat treatments were needed to form Ni$_4$Ti$_3$ precipitates to increase transformation temperatures. Furnace-cooling and additional aging heat treatment resulted in multi-stage martensitic transformation due to chemical and stress inhomogeneities in the microstructure. Aging the controlled furnace cooled material at 400 °C for 48 hours resulted in the highest transformation temperatures among all processing conditions due to the combination of Ni$_3$Ti precipitates and coarsening of the Ni$_4$Ti$_3$ precipitates. However, since overaging results in a loss of coherency of the precipitates, dimensional stability during isobaric thermal cycling was negatively impacted.

14. “Martensitic Transformation Characteristics of CoNiGa High Temperature Shape Memory Alloys”
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Current practical uses of shape memory alloys (SMAs) are limited to below 100 °C which is the limit for the stable transformation temperatures of most commercially successful SMAs, such as NiTi and Cu-based alloys. In the last few years, the CoNiGa system has emerged as a new ferromagnetic shape memory alloy with some compositions exhibiting high martensitic transformation temperatures, which make CoNiGa a potential high temperature shape memory alloy (HTSMA). In this study microstructural evolution and martensitic transformation characteristics of Co$_{26}$Ni$_{23}$Ga$_{27}$ and Co$_{30}$Ni$_{23}$Ga$_{30}$ (in at.%) high temperature shape memory alloys (HTSMA) were investigated in as-cast and hot-rolled conditions as a function of different heat treatments. Heat treatment conditions were selected to introduce single, two, and three phase structures, where two precipitate phases (ductile γ and hard γ) do not martensitically transform. The effects of these precipitates, and associated compositional changes in the matrix, on the transformation temperatures and microstructural evolution during thermal cycling...
were revealed. The most cyclically stable compositions with narrow transformation hysteresis (<40°C) were identified among those obtained after the selected heat treatments. These compositions show transformation temperatures in the range of 100°C to 250°C. M, temperature linearly depends on the valence electron concentration (e/a) of the matrix, only if the Ga content is constant. For a given e/a ratio, the higher the Ga content is, the higher the transformation temperatures become. The samples with narrow transformation hysteresis demonstrate reversible martensitic transformation in constant-stress thermal cycling experiments. However, their crystallographic texture should be engineered to increase the transformation strain levels, and γ content should be reduced to improve the cyclic reversibility.

15. “SMA Properties for Damping in Civil Engineering (Earthquake and Stayed Cables Mitigation)”
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The CuAlBe and NiTi are studied for their guaranteed application in Civil Engineering. For instance, in mitigation of oscillations induced by earthquakes in family houses or by or by oscillations induced by wind/rain/traffic in stayed cables for bridges. The CuAlBe and NiTi are studied for quake mitigation and, the NiTi, for damping of stayed cables. The mainly requirements of each application are: for quakes and replicas near 1000-2000 oscillations, 30 or 40 years previous to quake without changes, the effects of summer-winter temperature wave, not relevant actions of SMA creep and self-heating when SMA works. Also, for damping of stayed cables several millions of working oscillations and similarly, not relevant actions of SMA creep and self-heating when SMA works. Some experimental analysis is devoted to temperature aging of NiTi at 373 K. The results suggest some advantages in damping when a mix of the aged /not-aged SMA wire.

16. “Calculation of Actuation Time of a Fast Heated Shape Memory Alloy Wire Drive”
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Time needed for producing a displacement of a massive body by a shape memory alloy (SMA) wire is calculated. It is assumed that the pre-tensioned wire is heated by an electric current pulse of a specified duration. The calculation shows that at fast heating by a very short pulse the time need to produce a displacement of a massive body is determined mainly by the inertia of the body and SMA wire itself. For slow heating this time is such that is needed to reach the temperature of the finish of the reverse transformation. For intermediate conditions of actuation the dependence of the actuation time on the mass of the body, which is moved by the actuator and on the duration of heating is obtained.
17. "Magneto-Thermo-Mechanical Characterization of Meta-Magnetic Shape Memory Alloys"
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Magnetic Shape Memory Alloys (MSMAs) are a special class of smart materials that have received great interest due to their capability of producing large strains in moderate magnetic fields. They are useful for applications such as sensors, actuators, magnetic refrigeration, and integration into MEMS (micro-electro-mechanical systems). A specific type of magnetic shape memory alloys are ternary Ni-Mn-X (X=In, Sn and Sb) and quaternary Ni-Co-Mn-X alloys which show meta-magnetic shape memory effect (MSME). These alloy systems reveal ferromagnetic properties at high temperature parent (P) phase whereas the magnetization dramatically drops upon phase transformation. Thus, they are paramagnetic (or anti-ferromagnetic) at low temperature martensite phase.

In this work, direct measurements of reversible magnetic-field-induced strain (MFIS) on a single crystalline Ni\textsubscript{50}Mn\textsubscript{36.5}Co\textsubscript{13.5} meta-magnetic shape memory alloy were attained, for the first time, in the course of magnetic field-induced martensitic phase transformation using a custom designed micro magneto-thermo-mechanical testing system. MFIS levels were reported as a function of temperature, magnetic field and external bias stress. To be able to detect a notable MFIS, it was necessary to apply an external bias stress in these materials since magnetic field cannot favor a certain martensite variant. Fully recoverable transformation strains up to 3% were detected under repeated field applications in the presence of different compressive stress levels up to 125 MPa. Moreover, magnetization response of this single crystalline alloy was characterized as a function of temperature, and simultaneous magnetic field and external bias stress. Transformation temperature vs. field phase diagrams was constructed as a function of bias stress level. Fully recoverable field-induced phase transformation (FIPT) was realized under up to 125 MPa during the magnetization vs. field measurements at various temperatures. It was observed that magnetic field and external stress have opposite effects on martensitic transformation temperatures. Thermal transformation hysteresis increased with increasing field and magnetic transformation hysteresis rose with the reduction in temperature under zero external stress. Bias stress caused widening in magnetic transformation hysteresis at all test temperatures. We attempted to rationalize these complex sequence of changes in transformation temperatures and hysteresis under coupled stress, temperature and magnetic fields in terms of the change in lattice friction, non-monotonous change in both lattice parameters and elastic constants of austenite and martensite as a function of magnetic field and temperature, and the effect of stress on lattice distortion prior to phase transformation.

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This presentation will review the corrosion behavior of smart materials. The number of alloy systems that exhibit shape memory characteristics has increased in the past decade. Similarly, the potential applications have steadily increased and as less expensive and more corrosion susceptible materials are used the need for information on corrosion behavior has similarly increased. The authors will discuss potential corrosion problems and review the corrosion literature for specific information on smart materials. Of particular concern will be localized forms of corrosion (pitting and crevice corrosion) and the possibility of environmentally assisted cracking (stress corrosion cracking or hydrogen embrittlement).
19. “Size Effect on the Phase Transformation of SMA Nanowires”
Francis Phillips¹, Fang Dong², Hongxing Zheng², Dimitris Lagoudas¹,²
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The low actuation frequency of Shape Memory Alloys (SMAs) is primarily driven by the inability of bulk SMA actuators to dissipate the latent heat of transformation. By reducing SMA actuators to the nanoscale, it is believed that the maximum actuation frequency should increase due to the ability to dissipate the latent heat of transformation more quickly. Reducing the size of SMA actuators also brings about a need to understand the phase transformation of nanoscale SMAs. Various works on SMA nanograins, nanocrystals, and thin films have found that nanoscale SMAs exhibit a size dependence on the phase transformation in that below a given size the phase transformation is suppressed. No works have yet been published indicating whether the phase transformation of SMA nanowires is affected by the nanoscale.

The focus of this work is to experimentally and numerically investigate the phase transformation of SMA nanowires. The SMA nanowires characterized experimentally are composed of In-21at%Ti and are fabricated through the mechanical pressure injection method. Through transmission electron microscopy it is found that nanowires ranging in diameter from 650 nm to 10 nm all exhibit a phase transformation. Furthermore, a numerical study using molecular dynamics simulations indicates that free-standing SMA nanowires should exhibit a phase transformation throughout the nanoscale, in agreement with the experimental results of this study. Also, by applying a constraint on the long axis of a transforming nanowire, molecular dynamics simulations indicate that the phase transformation is suppressed, which is in agreement with expectations of a size effect based on previous works.

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The deformation of martensitic NiTi was investigated under tension and compression loading utilizing single crystals. The single-crystal samples were heat treated to achieve a martensitic state at room temperature. Using advanced digital image correlation techniques, the local strain fields were established during transition from multiple martensite variants to the formation of a single variant (detwinning). We use advanced digital image correlation techniques at multiple magnifications to reveal deformation information at different length scales. The tensile loadings preclude the study of plastic deformation to large strains due to fracture while compression experiments provide insight in the plastic flow regime to strains near 14%. Of particular interest is the [001] orientation which can undergo twinning but limited slip. The digital image correlation results pinpoint the precise stress levels corresponding to the onset of detwinning and to localization of plastic flow. The results provide insight into the occurrence of a reverse detwinning mechanism prevalent under unloading conditions that was systematically investigated with increasing levels of strain.
NiTi based Shape Memory Alloys (SMAs) have the ability to produce very high actuation strain, stress and work output as a result of reversible martensitic phase transformations; however, their high temperature commercial applications have been limited (below 100°C) due to their low transformation temperatures or unsatisfactory shape memory properties. In order to overcome those handicaps, NiTi is alloyed with ternary elements such as Pd, Pt, Au, Hf and Zr to make it display shape memory behavior at higher temperatures. Among those, Ni-Ti-Hf is the most promising alloy family due to its low production cost. On the other hand, Ni-Ti-Hf suffers from unstable shape memory behavior and lack of superelasticity due to its low strength and high transformation hysteresis.

In this study, chemical alloying and thermo-mechanical treatments have been utilized to tailor the mechanical and shape memory properties of the NiTiHf high temperature shape memory alloys. Extensive mechanical characterization studies have been conducted to determine the shape memory behavior of thermomechanically treated NiTiHf alloys. It has been revealed that transformation temperatures and mechanical response can successfully be adjusted by precipitation formation. Precipitates can alter both the composition and the strength of the matrix where stable superelastic and shape memory behaviors with low transformation hysteresis at temperatures above 100 °C can be observed in NiTiHf alloys.
Recently, we have found that some NiMn-based ordered bcc alloys, such as the NiMnIn and the NiMnSn alloys, show a unique transformation from a ferromagnetic parent (P) to a weak magnetic martensite (M) phase and that a magnetic field-induced transformation from the M to the P phase appears.[1-3] Furthermore, the shape memory (SM) effect due to the magnetic-field induced reverse transformation, namely, metamagnetic SM effect, can be obtained using this transition [3,4]. In this presentation, the magnetic and martensitic transformation properties in the metamagnetic SM alloys will be reviewed and some recent works on powder metallurgy [5], kinetic arrest phenomenon[6,7] and crystal structure of the layer ed martensites[8] will be introduced.

[8] M. Nagasako et al., to be submitted

Ferromagnetic shape memory alloys as Ni-Mn-X (X=In,Sn,Sb) exhibit a magnetostructural first order phase transition from ferromagnetic austenite to para-/antiferromagnetic-like martensite. In these metamagnetic alloys, the direct transformation shows isothermal characteristics, whereas the reverse one is athermal, as are both, direct and reverse, in conventional ferromagnetic shape memory alloys. The different character of direct and reverse transformations, together with recent results on the entropy changes associated to the phase transformation, allow us to conclude that the transition is driven by the first order lattice distortion, whereas the change of magnetic ordering is a concomitant effect accompanying the lattice modification, opposing the direct transformation and promoting the reverse one. The relaxation of magnetization and electrical resistance, reported in the “arrested” state of the direct magnetostructural transition under external magnetic field is an intrinsic property of the direct transformation and does not require the application of an external field or the “arrest” of the transition.
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TUESDAY, June 22  9:30 - 9:50

“Magnetic Field-Induced Large Strain in Alloys and Ceramics Exhibiting Martensitic Transformations”
Tomoyuki Kakeshita, Tomoyuki Terai and Takashi Fukuda
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More than a decade has passed since the discovery of a large magnetic field-induced strain (MFIS) in a Ni-Mn-Ga ferromagnetic shape memory alloy, and many new systems exhibiting a large MFIS have been reported up to now. In the presentation, we summarize our study on the MFIS related to martensitic transformations in alloys and ceramics.

The MFIS related to martensitic transformation can be classified into two types. The first type is the MFIS caused by the rearrangement of martensite variants, which occurs below the martensitic transformation temperature $T_M$. The martensite phase of Fe3Pt, Fe-30.2Pd, Ni2MnGa alloys, and also antiferromagnetic ceramics of CoO show this type of MFIS. The condition for the appearance of this type of MFIS is universally explained by the relation among the magnetocrystalline anisotropy, the twinning stress and the twinning shear of the martensite phase, regardless of temperature, orientation and magnetic property. The second type is the MFIS caused by the magnetic field-induced reverse martensitic transformation. A typical example of this type of MFIS is the melting of charge ordered phase in Nd0.5Sr0.5MnO3 by the application of magnetic field. In this case, the magnetic energy difference between the parent and martensite phase determines the condition for the appearance of the MFIS. In addition, we will show a large elastic strain in an ordered Fe3Pt, which is not due to martensitic transformation but due to a very small value of elastic constant $c'$.

TUESDAY, June 22  9:50 - 10:10

“The Consequences of Antiferromagnetism on Magnetic Shape Memory and Magnetocaloric Effects in Martensitic Heuslers”
M. Acet$^1$, S. Aksoy$^1$, A. Dannenberg$^1$, M. E. Gruner$^3$, P. Entel$^1$, L. Mañosa$^2$, and A. Planes$^2$

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The results of diffuse neutron polarization experiments on Ni-Mn-based martensitic Heusler systems show the presence of short-range antiferromagnetic correlations in the temperature-range between the martensite-start temperature and the lower-lying martensite-Curie temperature. On the other hand, ferromagnetic resonance experiments just below the martensite Curie temperature indicate the presence of both ferromagnetic and antiferromagnetic long-range interactions. Knowing the nature of magnetic coupling in the various magnetic and crystallographic states of these alloys allows us to understand the origins of various effects observed in martensitic Heuslers such as exchange-bias, kinetic arrest, etc. Furthermore, it also allows us to understand how the various types of magnetic interactions affect the magnetic shape-memory and magnetocaloric properties. We present results of experiments mentioned above and discuss in particular the consequences of the presence of antiferromagnetism on magnetic shape-memory and magnetocaloric effects in martensitic Heuslers.
Ferromagnetic Ni-Mn-based shape memory alloys undergo martensitic transformation and exhibit magnetic shape memory, magnetic-field-induced strain and kinetic arrest. Thermal expansion measurements in the temperature vicinity of the martensitic transformation can reveal volume differences between austenite and martensite phases. Thermal expansion experiments carried out in the presence of a magnetic cooling-field (applied in the austenite state with which the sample is cooled through the martensitic transition), can provide information on the properties of martensite nucleation. We report on the results of temperature-dependent strain and neutron diffraction studies in Ni-Mn-based Heusler alloys and discuss the influence of the applied magnetic field on martensite nucleation and the occurrence of austenite arrest.

First-principles calculations demonstrate that the martensitic tendencies and respective magnetic properties of the Heusler alloys which show the magnetic shape memory effect. The appearance of twinned modulated martensite over a sufficiently large temperature range below the martensite transformation temperature is a necessary prerequisite for the ability of the alloy to display large magnetic field-induced length changes, which may be exploited in technological devices. In this contribution we mainly focus on the intrinsic properties of X_2YZ compounds and related alloys by comparing Ni-Mn-based alloys with Ni-Mn-free systems. We show that four features determine most of these properties: (i) The hybridization of the electronic states of the transition-metal elements on octahedral and tetrahedral lattice sites, (ii) the position of the Fermi level (i.e. the number of valence electrons per atom), (iii) the degree of metallic vs. tetrahedral bonding and (iv) the degree of disorder in the alloys. In particular, the tetragonal arrangement of the atoms in martensite and disorder lead to competing ferromagnetic and antiferromagnetic interactions which are not favorable for the magnetic shape memory effect but favor the magnetocaloric effect in the same alloy series.
Designing magnetic shape memory materials with practicable engineering applications requires a thorough understanding of their electronic, magnetic, and mechanical properties. Experimental and computational studies on such materials provide differing perspectives on the same problems, with theoretical approaches offering fundamental insight into complex experimental phenomena. Many recent computational approaches have focused on first-principles calculations, all of which have been successful in reproducing ground-state structures and properties such as lattice parameters, magnetic moments, electronic density of states, and phonon dispersion curves. With all of these successes, however, such methods need to include the effects of finite temperatures, and the effects of stoichiometry; the effects which are critical in understanding how these properties couple to the experimentally-observed martensitic transformation. To this end, we apply the quasi-harmonic theory of lattice dynamics to predict the finite-temperature mechanical properties of Ni-Mn-In magnetic shape memory alloy. We employ first-principles calculations in which we include vibrational contributions to the free energy. By constructing a free energy surface in volume/temperature space, we are able to evaluate key thermodynamic properties such as entropy, enthalpy, and specific heat. We further report the elastic constants for the austenite and martensite phases and evaluate their role as a driving force for martensitic transformation.

In recent years, ferromagnetic Heusler Ni-Mn-X (X= In, Sn, Sb) alloys have attracted much attention in view of their unique properties such as the shape memory effect, giant magnetocaloric effect (MCE), large magnetoresistance and other interesting magnetic properties like a coupled magnetostructural phase transition [1-3]. Moreover two types of MCE (conventional and negative) are observed experimentally in Ni-Mn-X alloys. The conventional MCE arises close an area of magnetic phase transition from a paramagnetic (PM) austenite to a ferromagnetic (FM) one. The origin of the inverse MCE is essential antiferromagnetic (AFM) correlations at a field of the coupled magnetostructural phase transformation from the FM austenite to a mixed AFM-FM martensite. The values of both types of MCE are compared with best magnetocaloric materials such Gd, Gd-Ge-Si, Mn-As, La-Fe-Si [2-4]. Besides, the Ni-Mn-X (X= In, Sn, Sb) alloys are more cheaper than rare-earth compounds and are also more environmentally friendly than Mn-As alloys. In this work we present the modeling of magnetic and magnetocaloric properties of Heusler Ni_{50}Mn_{34}In_{16} alloy by the help the Monte Carlo simulations.

In the proposed model, we consider the three-dimensional realistic cubic lattice of Heusler Ni-Mn-X (X= In, Sn, Sb) alloys. This lattice may be considered as four interpenetrating fcc sublattices with atoms X, Mn and Ni, at locations (0, 0, 0), (½, ½, ½), (¼, ¼, ¼), respectively [5]. For non-stoichiometric alloys the excess of Mn atoms are located at In's crystallographic sites and a configuration of these atoms is set randomly. In our model, we consider FM and AFM interactions between Mn and Ni atoms on a cubic and tetragonal unit cell. The interaction between In atoms is negligible. Values of magnetic exchange integrals have been taken from first-principle ab initio calculations for Ni_{50}Mn_{34}In_{16} alloy [6]. So, the magnetic subsystem is described by mixed 3-5 state Potts model which allows to simulate the magnetic phase transition [6]. Here, “3” and “5” means numbers of spin states of Ni and Mn atoms, respectively. Because, the spin moments of Ni and Mn atoms are S=1 and S=2, and 2S+1 states are possible. For the modeling of the structural transformation from the austenitic phase to the martensitic phase, we choose the degenerated three states Blume-Emery-Griffths model [6]. By the help of theoretical model the
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thermomagnetization curves, magnetic and total specific heats and inverse and conventional MCE of Ni$_{50}$Mn$_{34}$In$_{16}$ are obtained. For a comparing with model results of MCE we also have simulated MCE by the help of thermodynamical Maxwell equations. It is shown that the model magnetocaloric quantities are closed to experimental results [2, 3].


TUESDAY, June 22 12:00 - 12:20

“Ab Initio Investigation and Thermodynamic Modeling of Co-Ni-Ga and Co-Ni-Al Shape Memory Alloys”
Raymundo Arroyave, Arpita Chari, Avinash Chivukula, Anchalee Junkaew
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Co$_2$NiGa and Co$_2$NiAl alloys have been receiving considerable interest due to their shape memory (SM) properties. While there have been many investigations on the mechanical and magnetic behavior of these materials, very little is known about the fundamental microscopic basis for the observed macroscopic behavior.

In the first part of the talk, we discuss the stability of Co$_2$NiGa and Co$_2$NiAl-based structures. The austenite phase is modeled as fully-ordered L2$_1$ and as partially-ordered B2 (through the use of special quasi-random structures). The transformation of the cubic austenite to the tetragonal martensite structure is investigated through Bain distortion paths as well as lattice dynamical calculations. Effects of temperature and configuration are incorporated through the use of Cluster Expansion Alloy Theoretic techniques. Analysis of the features of the electronic structure are then mapped to the observed metastability of the cubic phases with respect to tetragonal deformations and comparisons are made with the much more studied Ni$_2$MnGa-based SMAs.

In the second part of the talk we will focus on the use of the first-principles calculations in combination with experimental information to develop accurate thermodynamic models ---based on the CALPHAD approach---for the Co-Ni-Ga ternary system. These thermodynamic models are then used to predict phase constitution as a function of alloy composition and temperature. It will also be shown how it is possible to develop thermodynamic models for the martensitic transformation by using experimental information on the transformation temperatures in off-stoichiometric Co$_2$NiGa alloys. Reliable thermodynamic models can be used in the computer-aided design of novel shape memory alloys based on this ternary system.

TUESDAY, June 22 13:50 - 14:10

“Superelastic Shape Memory Thin Films”
Eckhard Quandt, Christiane Zamponi, Rodrigo Lima de Miranda

Superelastic shape memory thin films are very attractive for medical applications in small dimensions due to the large obtainable strains, the constant stress level and their biocompatibility. Using photo lithography thin film devices can be fabricated with very small feature sizes and complex geometries. This presentation will review fabrication issues, properties and potential applications of superelastic TiNi films.
“Solid State Diffusion Synthesis of NiTi”
Yinong Liu, Hong Yang, Jamaluddin Laeng, Hanim Mohd Zaki
Laboratory for Functiona Materials, School of Mechanical Engineering, The University of Western Australia, 35 Stirling Highway, Crawley, WA6009, Australia

This study investigates the phase formation of NiTi via solid-state diffusion reactions, a situation commonly encountered in powder metallurgy processing and fabrication of porous NiTi. A diffusion model based on the binary Ni-Ti phase diagram is proposed. The model predicts the formation of NiTi$_2$ and Ni$_3$Ti prior to the formation of NiTi. It also predicts the formation of two B2-NiTi phases of different compositions, corresponding to the two solvi of the B2 phase region in the binary phase diagram. These predictions are confirmed experimentally by means of scanning electron microscopy, x-ray energy dispersive spectroscopy and x-ray diffraction. The experimental work reveals that sintered samples consist of NiTi$_2$, NiTi and Ni$_3$Ti in co-existence. Such co-existence is not expected from the equilibrium phase diagram. Thermodynamic analysis indicates that formation of NiTi is not favoured in primary reactions between Ni and Ti, but can be formed via secondary reactions involving primary reaction products NiTi$_2$ and Ni$_3$Ti. Such reactions are difficult in solid state due to the difficulties of long-distance diffusion required. The synthesised alloys are found to exhibit much reduced martensitic transformation intensity, implying low transformation volume.

“Microstructure Formation and Hysteresis in Shape Memory Alloys”
O. Kastner$^1$, G.J. Ackland$^2$ and Gunther Eggeler$^1$
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$^2$School of Physics, University of Edinburgh, UK

Shape memory alloys (SMA) exhibit a number of features which are not easily explained by equilibrium thermodynamics, including hysteresis in the phase transformation and “reverse” shape memory in the high symmetry phase. Processing can change these features: repeated cycling can “train” the reverse shape memory effect, while changing the amount of hysteresis and other functional properties. These effects are likely to be due to creation of persistent localized defects, which are impossible to study using non-atomistic methods. In the talk we present a molecular dynamics simulation study on this behavior. To simulate free evolutions of domain structures atomic test assemblies must be sufficiently large and long computation run-times are required. In favor of longer run-times, we focus here a two dimensional binary Lennard-Jones model which represents a reliable qualitative model system for martensite/austenite transformations. We investigate the formation of microstructure and the evolution of defect structures in simulations of cyclic transformation/reverse transformation processes. The simulations show that the transformation proceeds by non-diffusive nucleation and growth processes and produces distinct microstructure.

Upon transformation, lattice defects are generated. These affect subsequent transformations and vary the potential energy landscape of the sample. If the sample is cycled through a series of forward/reverse transformations, the amount of defects in each phase accumulates. Defects act as nucleation sources for the transition. Moreover, the location of the defects can be preserved through the cycling, providing a memory of previous structures. Employing thermodynamic arguments we explain how the energetic implications of a defect structure gives rise to pronounced hysteresis and functional fatigue.

Molecular dynamics simulations of martensitic microstructure. (a): Zirconium (during transformation), 3D, 3.5 Million atoms.
(b): Lennard-Jones crystal, 2D, 160,000 atoms
Shape memory alloys (such as NiTi) have fascinated scientists for their ability to “remember” their original shape when heated, by undergoing a martensitic phase transformation from one crystal structure to another. Their thin-film embodiment has drawn much attention due to their potential use as actuation materials in microelectromechanical systems (MEMS). NiTi thin films are commonly sputtered in an amorphous form and require a high-temperature crystallization step to create their crystalline (actuating) form. The impact of this crystallization step is quite significant because it is highly dependent on temperature and composition. We have studied the crystallization process using in situ heating transmission electron microscopy. This talk will present our observations and a quantitative description of the crystallization kinetics using the Johnson-Mehl-Avrami-Kolmogorov (JMAK) theory. The combination of our experimental observations with the JMAK theory has rendered us able to predict the microstructure (particularly, the average grain size) over a broad range of temperatures. It has been found that the grain size controls the extent of the martensitic transformation. Such insights can contribute to the development of these materials for MEMS with optimal properties.
Biomedical shape memory alloys are required to have superior corrosion resistance, biocompatibility and excellent shape memory property. Recently, β type Ti alloys composed of non-toxic elements have attracted attention as biomedical shape memory and superelastic materials. The β-Ti alloy is one of the most attractive candidates for biomedical shape memory alloys. Ti-Nb-X (X = Zr, Ta, Mo, Au, Pt, Al, Ga, Ge, O, N) and Ti-Mo-X (X = Ta, Nb, Zr, Au, Pd, Pt, Al, Ga, Ge) alloys have been developed and their shape memory effect and superelasticity were investigated systematically by the present authors’ group for about nine years. Low temperature annealing and aging treatment were effective in improving shape memory and superelastic behavior. Addition of alloying elements such as Zr, Ta, Mo, Au, Pt, O and N was also effective in stabilizing the superelasticity. The unique deformation texture and recrystallization texture induced strong anisotropy in shape recovery strain. In this presentation, the above topics relating to the β type Ti alloys will be reviewed.

**“Thermoelastic Martensitic Transformation in High-Strength Single Crystals”**

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The level of strength properties of a high-temperature phase in Ni-Ti, Ni-Fe-Ga-(Co), Co-Ni-Ga, Co-Ni-Al, Ni-Mn-Co-In single crystals, undergoing thermoelastic martensitic transformations, defines the values of thermal and mechanical hysterises, superelasticity window and resistance to cyclic loads. High-strength state is achieved by changing the chemical composition, crystal axis orientation, precipitation of dispersed particles of secondary phases. It is shown, that in high-strength crystals considerable growth of superelasticity window and reduction of a mechanical hysteresis as compared to low-strength crystals is observed. In a high-strength state the temperature intervals of superelasticity are 170 K in Ti-Ni crystals, 250 K in Co-Ni-Al crystals and 300-450 K in Ni-Fe-Ga and Co-Ni-Ga crystals. Firstly, it is achieved, through the choice of crystal axis orientation close <001> direction in which a <100> [110] dislocation slip in a high-temperature phase is suppressed because of Schmid factor equals to zero. Secondly, it is reached through the precipitation of disperse particles in the size from 5 to 50 nm, which do not undergo martensitic transformations and strengthen a high-temperature phase.

It is established that the dispersed particles lead to degeneration of the orientation dependence of shape memory effect and superelasticity, which takes place in monophase crystals. The new approach to explain the characteristics of thermoelastic martensitic transformations in heterophase crystals develops. This approach is based on the ideas of formation of “geometrically-necessary” twins which appear to retain the compatibility between the martensitic deformation of matrix and elastic deformation of particles. This explains the dependence of shape memory effect and superelasticity on the size, volume fraction and number of particle variants.

In analyzing the dependence of transformation strain and mechanical hysteresis value on external stress level in high-strength crystals it is necessary to take into consideration the influence of external stress on lattice parameters of high-temperature phase and martensite. It in turn can define dependence of fine structure of martensite crystals and twin density on the level of external stress.

For the first time conditions at which value of shape memory effect and superelasticity can exceed lattice strain at martensitic transformations are established. The mechanism of this phenomenon connected with reversible mechanical twinning of martensite single crystals is suggested.

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**“Superelasticity and Two-Way Shape Memory Effect in Ni-Fe-Ga-Co Single Crystals”**

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Single crystals of Ni$_{49}$Fe$_{18}$Ga$_{27}$Co$_6$ oriented along [001] exhibit perfect superelasticity in compression, with 5.5% recoverable strain consistent with formation of stress-induced L1$_0$ martensite. After a series of superelastic cycles at different temperatures between 300 and 450K, totalling only 18 cycles, a complete two-way shape memory effect (TWSME) is induced, with 5.5% spontaneous compression strain upon cooling. The induced TWSME is able to resist opposing tensile stresses up to 20 MPa, for which no spontaneous strain is recorded on cooling. The maximum work performed against the opposite stress is of the order of 2·10$^5$ J/m$^3$. Further experiments show that the TWSME is mainly induced in the superelastic cycles performed at high temperatures; for instance, a series of 14 cycles performed at temperatures in the range 300-410K only induces a TWSME of 40% of the superelastic strain induced during cycling; while 4 additional cycles at 433K raise this value to nearly 100%. The origin of the induced TWSME will be discussed in terms of dislocations created by superelastic cycling, investigated by TEM, and stabilized martensite retained after cycling.

**“Superelastic Tensile Behavior of Ni-Mn-Ga Alloys”**

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The ferromagnetic shape memory Ni-Mn-Ga alloys demonstrate the extraordinary actuation ability in the magnetic field. Whereas many mechanical studies in compression mode have shown that they also exhibit a well-pronounced superelasticity, the mechanical behavior of these alloys in tensile experiments has been rarely addressed. The latter experiments were hindered by the enhanced brittleness of these alloys even in the single crystalline form.

In this work, we review the previous results on the superelastic properties of Ni-Mn-Ga alloys including their theoretical treatment, and present the original results of tensile tests carried out using two single crystals with transformation temperatures of about 300 K (A1) and 670 K (A2). The measurements are made with a DMA Q800 analyzer which made it possible to register from the same sample the temperature dependencies of elastic modulus and internal friction in the dynamic tensile mode, as well as stress versus strain at a constant temperature $T_{\text{exp}}$ and strain versus temperature at zero stress in the static tensile mode. The temperature dependencies of elastic modulus demonstrate its softening in the cubic phase and typical anomalies produced by martensitic and intermartensitic transformations. Particularly, the multistep superelasticity of about 10% and one-step superelasticity of about 7% have been obtained in alloys A1 and A2, respectively. The quasi-equilibrium stress – temperature phase diagram of L2$_2$-5M, 5M-7M and 7M – 2M phase transitions in A1 alloy is constructed while the phase diagram of L2$_1$ – 2M transition in the case of alloy A2 was dependent on the stress-strain cycling. The results are compared with those obtained previously in compression mode.
“Huge Superelasticity and Magnetic Properties in Fe-Ni-Co-Al based Shape Memory Alloys”
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Ferrous shape memory alloys (SMAs), such as Fe-Mn-Si [1] and Fe-Ni-Co-Ti [2, 3] are commercially attractive because they are cheaper and show better workability than Ni-Ti based SMAs. The Fe-Mn-Si based alloys, which exhibit the SM effect associated with γ(fcc) to ε(hcp) martensitic transformation are now used for some SM applications, such as pipe couplings and fishplates. In previous ferrous SMAs, however, one of the most serious drawbacks for practical use is that superelasticity (SE) can hardly be obtained at room temperature. Recently, we found that a large superelasticity of about 13%, which is almost twice than that of Ni-Ti alloy, appears at room temperature in a pollicrystalline Fe-Ni-Co-Al-Ta-B alloy due to a thermoelastic γ / α'(bct) transformation [4]. Furthermore, this ferrous alloy shows some unique magnetic properties, such as a large reversible change in magnetization in tensile loading and unloading and a magnetic-induced strain of about 1% at room temperature. Very recently we also confirmed a good SE in a Fe-Ni-Co-Al-Nb-B alloy. In this presentation, we will describe these SE and magnetic properties in the Fe-Ni-Co-Al-(Ta, Nb)-B alloys and also discuss a mechanism of their huge SE.


“Multiple Length Scale Analysis of the Dual Hysteresis Observed in NiMnGa Shape Memory Alloys”
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The stress-induced martensitic transformation in NiMnGa shape memory alloys (SMAs) can proceed via successive martensite-to-martensite transitions referred to as inter-martensitic transformations. Limited studies on NiMnGa characterize the fundamental thermo-mechanical response and the literature primarily focuses on the effects of applied magnetic field. The current work undertakes a comprehensive study including the shape memory effect (SME) and pseudoelastic (PE) response. The transformation path is resolved at the meso-scale with an extensometer and at the micro-scale utilizing in-situ digital image correlation (DIC) analysis within the gage length of the extensometer. The stress-free thermal-induced martensite transformation has been studied extensively in these classes of SMAs. Martensite crystal structures can exhibit 10M or 14M modulation, as well as, a non-modulated structure. Previous works outline three groups of NiMnGa alloys: Ms ~ 200K, Ms near room temperature, and Ms high above RT. Here the SME and PE responses are investigated in alloys with Ms near and above room temperature. Multiple stages are observed in the strain-temperature and stress-strain responses of [001] oriented single crystals loaded in compression - indicative of an initial austenite-martensite transformation followed by successive inter-
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Martensitic transitions. The first stage exhibits a narrow hysteresis, whereas, the hysteresis increases fourfold during the second stage. Though differential hysteresis levels arise, the strains are fully recovered. Full field, micro-scale DIC measurements expose that the initial transformation proceeds via band formation in the PE case. Furthermore, the results support multi-variant interaction. At a higher magnification, a second transition is revealed within the band. In contrast to the bands observed during the initial stage, the second stage proceeds heterogeneously. Remarkably, in the SME case, the initial transformation proceeds isothermally compared to the second. The disparity in hysteresis levels and isothermal transition can be rationalized based on dissimilar transformation paths. The 14M structure forms during the first stage and non-modulated martensite during the second. The results point to a fast-response with narrow hysteresis can be attributed to the underlying inter-martensitic transformations in these classes of NiMnGa alloys.

“The Role of Interfaces in Bulk and Thin Film Magnetic Shape Memory Alloys”
Sebastian Fähler
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Key properties of magnet shape memory (MSM) alloys are controlled by various types of interfaces: twin boundaries, domain walls, habit planes. Since thin films add two more interfaces, at the first glance everything appears to be more difficult in thin MSM films. Here we will show that in particular epitaxial MSM films help for a better understanding of MSM alloys in general. As a first system, FePd is selected. Strained coherent growth on various substrates allows us to adjust the tetragonal distortion from c/a_{bcc} = 1.09 to 1.39, covering most of the Bain transformation path from fcc to bcc crystal structure. Hence in these films intermediate stages during a martensitic transition are frozen by the substrate constrain. This allowed a detailed study of their intrinsic properties, relevant for the MSM effect. It is observed that Curie temperature, orbital magnetic moment, and magnetocrystalline anisotropy vary over broad ranges [1].

As a next system epitaxial Ni-Mn-Ga films are examined. Coexistence of austenite, adaptive 14M phase, and tetragonal martensite is observed over a broad temperature range. Since the substrate acts as an absolute reference system, the orientation relationship between these phases can be probed. It is show that the modulated martensite can be constructed from nanotwinned variants of the tetragonal martensite phase. By combining Khachaturyan’s concept of adaptive martensite with branching of twin variants, the key features of modulated phases from a microscopic view can be explained. This includes metastability, the sequence of 6M-10M-14M-NM intermartensitic transitions, and the magnetocrystalline anisotropy [2]. Though the focus of this talk is on experiments, these are compared with first principle calculations and continuum models. With this, some gaps in the understanding of MSM alloys at different length scales can be closed.

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“Magnetic Anisotropy and Magnetoelastic Coupling in Ni-Mn-Ga Magnetic Shape Memory Alloys”
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Magnetically induced reorientation (MIR), one of the magnetic shape memory (MSM) effects, results up to 11% deformation in moderate magnetic field. The reorientation occurs due to twin boundary motion in magnetic field. MIR occurs if the magnetic energy, which is ultimately determined by magnetic anisotropy, exceeds energy needed for twin boundary motion. Necessary conditions for the effects are therefore high magnetic anisotropy and high mobility of twin boundaries. Magnetic anisotropy of Ni-Mn-Ga martensites is well documented and as the intrinsic property it cannot be so easily manipulated by. On the contrary, the high mobility of the \{110\} twin boundaries caused by shear instability, may strongly depend on the state of material and its thermal history. Recently, it was reported nearly tenfold increase of the mobility as specified by twinning stress. This extreme mobility is puzzling. We investigate elastic constants and shear instability behavior in austenite prior transformation to martensite as a function of temperature and magnetic field using different ultrasound methods as pulse echo and resonant ultrasound spectroscopy. We observed strong effect of magnetic field on elastic damping, elastic anisotropy and shear softening (as indicated by c\(') constant). This points out to strong magnetoelastic coupling prior transformation to martensite. In comparison with other ferromagnetic shape memory alloys, which do not exhibit a strong dependence on magnetic field and simultaneously also no MSM effect, the observed magnetically induced instability seems to suggest a new guiding principle for searching new MSM alloys.

WEDNESDAY, June 23

“Elastic Properties of Ni\textsubscript{2}MnGa from First-Principles Calculations”
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Elastic properties of Ni\textsubscript{2}MnGa in both austenitic and martensitic structures are determined by using ab-initio methods based on density functional theory (DFT) within the spin-polarized generalized-gradient approximation. Tetragonal shear elastic constant C\textsuperscript{\textprime} takes very small value in the austenitic phase, indicating the elastic instability resulting in phase transition to martensitic structure. Isotropic mechanical properties such as bulk modulus, shear modulus, Young’s modulus and Poisson’s ratio are predicted. The trend of the Debye temperatures calculated for three structures of Ni\textsubscript{2}MnGa is compatible with that of the experiment.
Shape memory alloys (SMAs), and in particular Nickel Titanium (NiTi) based ones, have seen increasing interests and applications in recent years in many branches of engineering and medicine, due to their special functional properties, namely shape memory effect (SME) and superelastic effect (SE), as well as to the good mechanical performances and biocompatibility. Due to this interest many research activities have been carried out with the aim of analyzing the thermo-mechanical responses of NiTi alloys as well as to develop proper numerical models which are able to predict their mechanical and functional behavior. However, from a material science point of view many aspects related to the mechanical properties of such class of material, such as fatigue and fracture behavior, are still unknown and much research should be carried out in order to better understand the role of thermo-elastic martensitic transformation on the mechanical performances of SMAs. An accurate knowledge of these topics is of major concern since it is essential to predict the functional and structural life, as well as to understand the failure modes of damaged structures.

In particular, some recent experimental researches [1-4] demonstrated that stress induced martensitic transformation occurs in front of the crack tip as a consequence of the high values of local stresses. Furthermore, the crack tip transformation behavior and the resulting stress distribution have been investigated by numerical analyses [5,6] as well as by proper analytical models [7-10].

In this work, the evolution of crack tip transformation region and stress distribution is deeply investigated, as a function of the main thermo-mechanical parameters of NiTi alloys, by a recent literature analytical model of the authors [10]. Furthermore, based on linear elastic fracture mechanics concepts, two different values of the stress intensity factors have been defined to describe the stress distribution in both transformed and untransformed region.

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“SMA in Damping for Earthquakes in Family Houses and in Stayed Cables for Bridges”
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The particular requirements for the use of SMA in dampers for family houses are determined and the properties of SMA quantitatively studied. In particular, the appropriate fatigue life, the invariance or reduced evolution after 20 or 30 years in a quiet or “no-working” state. Also, the increase of length in cycling is analysed. Two alloys are studied for this application: CuAlBe and NiTi. The dampers are used in a steel portico under the action of an actuator (a hydraulic piston, computer controlled). The simulation study and the experimental “realistic” study in the portico shows the highly effective results on damping using SMA dampers in light civil steel structures under the action of earthquakes. In the particular case of stayed cables a deep study of fatigue-life is performed to ensure the conditions needed for the larger number (several millions) working cycles. Also, for working under the wild temperature effects and under the self heating actions. The long time aging of NiTi, modifying the transformation temperatures and the critical stresses of transformation, is of high interest. It establishes the advantages of one mixture of wires (aged and “as furnished”) for dampers situated in the free surroundings as in bridges. An application of the SMA dampers is realized in two cables: cable No. 1 in ELSA–EU facility (Ispra–Italy) and in LCPC (Nantes – France). Several examples show the availability and highly positive effects of SMA dampers in the oscillatory behaviour of realistic cables (i.e., the oscillation amplitude was reduced to 1/3). Using a bilinear model with the Clausius-Clapeyron coefficient (ds/dT) the ANSYS simulation shows excellent coherence with the experimental results. The results of these two SMA applications are interesting and new. Focussing only in one of them seems a reduction of the positive target in SMA.

“Bulk and Porous Metastable Beta Ti-Nb-Zr(Ta) Alloys for Biomedical Applications”
V. Brailovski, P. Terriault, D. Coutu, and T. Georges
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Metastable beta-titanium alloys combine exceptionally low Young’s modulus and high corrosion resistance, thus attracting special interest in prospect of their applications as biomedical implant material. In this work, Ti-Nb-Zr(Ta) ingots were manufactured by vacuum argon melting. The obtained ingots were divided in two batches: the first subjected to cold rolling (CR) from 30 to 85% of thickness reduction and subsequent annealing in the 450 to 900 deg.C temperature region and the second, atomized to produce 100 mcm size powders. The powder was used to manufacture open-cell porous material. Regardless of the CR intensity, Ti-(18...20)Nb-(5...6)Zr (at%) samples subjected to 600 deg.C (1h) annealing showed a significant material softening due to the stress-induced martensitic transformation. The 600 deg.C annealing corresponded to transition from perfect polygonized dislocation substructure to the fine-grained recrystallized structure. Young’s modulus of these alloys varied between 45 and 55 GPa and yield stress, between 300 and 500 MPa. The obtained Young's moduli, which are comparable to 55-66 GPa of concurrent beta-titanium alloys and 45-50 GPa of superelastic Ti-Ni alloys, come close to those of cortical bones. Compression testing of the porous material as a function of porosity (from 45 to 66%) and cell size (d50 from 300 to 760 mcm) showed the following properties: Young’s modulus from 7.5 to 3.7 GPa, which comes close to those of trabecular bones, and ultimate compression strength, from 225 to 70 MPa, which is twice as high as UCS of bones.
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WEDNESDAY, June 23 15:35 - 15:55

“Correlation of the Defect Formation in Thin Polyelectrolyte Films with the Transformation Behavior of Polycrystalline NiTi Substrates”
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The present work reports on the mechanical stability of thin PAA/PAH (polyacrylic acid/polyallyamine hydrochloride) polyelectrolyte films deposited on NiTi substrates. The mechanical properties of thin polyelectrolyte layers in fluid environments are of particular interest, since thin polyelectrolyte films are promising coatings to reduce the Ni-release of NiTi alloys in biomedical applications. A miniature load frame was used to apply monotonic and cyclic strains of 5% and 3%, respectively, accompanied by detailed in-situ microscopic investigations of the strained thin films. Macroscopic and microscopic defect localizations were determined by means of digital image correlation and EBSD (electron back scattered diffraction) techniques, in order to relate the defect formation within the films to the transformation behavior of the NiTi-substrate.

The results of the current study showed that, in contrast to a monotonic strain, cyclic strains result in the formation of laminar defects within the polyelectrolyte films. Digital image correlation and EBSD-measurements revealed that few defects were located within areas of maximum local strains while the majority of the observed defects emerged in areas of high local strain gradients directly at or at least in the vicinity of grain boundaries.

For a better understanding of the mechanisms determining defect formation, crystallographic data obtained from the EBSD-measurements were correlated with the defect distribution. EBSD data supplemented with laser scanning microscopy revealed that defect localization in the polyelectrolyte films can be attributed to recurring changes in topography and local strains resulting from constraints at grain boundaries showing distinct crystallographic misorientations.

WEDNESDAY, June 23 15:55 - 16:15

“Superelastic Response of NiTiHf-Based Shape Memory Alloys”
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There is an increasing interest in High Temperature Shape Memory Alloys (HTSMAs) that have the ability to produce high actuation strain, stress, and work output at temperatures above 100 °C for industrial applications. In this study, superelastic response of single and polycrystalline NiTiHf-based HTSMAs will be reported. Effects of heat treatments, orientation and testing temperature on transformation strain, stress and hysteresis as well as cyclic stability will be revealed. It will be shown that precipitation hardening by suitable heat treatments could increase the material strength to result in stable and “good” superelastic behavior at high temperatures.
“Production and Mechanical Characterization of Ni-rich NiTi Porous Shape Memory Alloys”

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Ni-rich (50.4\%Ni) Ni-Ti porous shape memory alloys with 30\% porosity level were produced using magnesium powder as a space holder via conventional powder metallurgy technique. The prealloyed powders were used instead of Ni and Ti elemental powders to prevent the formation of secondary phases. NiTi with magnesium powders and a binder were cold pressed uniaxially and sintered using a vertical furnace under controlled atmosphere. Micropore analysis together with heating-cooling at different stress levels and loading-unloading at room temperature experiments were conducted to understand the effect of production using magnesium as pore forming powder on the shape memory and pseudoelastic behavior of the alloy. It was demonstrated that the samples have interconnected open pores and the pores were spherical in shape with an average pore sizes of 400\textmu m. The results of the heating-cooling experiments at different stress levels were promising such that no irrecoverable strain was observed under 75\text{MPa}. 
“Shape Memory Thin Film Actuators”
Manfred Kohl
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The research on shape memory alloy (SMA) thin films is mainly motivated by the high energy density and favourable scaling behaviour of their mechanical properties upon miniaturization. These features are considered to be crucial for applications in the field of micro- and nano-electro-mechanical systems (MEMS, NEMS). In this presentation, recent developments in the materials, design, fabrication and performance of selected SMA thin film actuators will be described.

SMA thin films of various chemical compositions have been fabricated by magnetron sputtering. For instance, ternary TiNi(Pd,Pt,Hf) thin films have been developed showing high transformation temperatures. Recent research concentrates on ferromagnetic SMA thin films based, e.g., on FePd and Ni-Mn-Ga, which exhibit thermo-elastic as well as ferromagnetic properties. The development of ferromagnetic SMA film actuators showing large magneto-strain effects similar to corresponding bulk systems is currently a hot topic of materials research.

For operation of high-temperature SMA film actuators, an optimum balance of power requirement and heat transfer times has to be found. Thermal design optimization of such actuators has been performed by coupled finite element simulations, which use a Tanaka-type macromodel for the thermo-elastic coupling including Joule heating, heat exchange effects and latent heats of transformation.

In order to describe the performance of ferromagnetic SMA film actuators, a fully coupled thermo-magneto-mechanical model has been developed and implemented in a finite element tool. In this case, the model makes use of Gibbs free energy expressions for a representative lattice element and the theory of thermally activated processes to derive evolution equations for the martensite phase fractions. Benchmark simulations reproduce the main features of bulk Ni-Mn-Ga single crystals observed in temperature-dependent magneto-strain as well as magnetization experiments. Current investigations are directed towards Ni-Mn-Ga thin film configurations, in which actuation is achieved by applying a magnetic field parallel to a tensile bias stress.

A number of technologies have been developed for fabrication of SMA film actuators. Si-based technologies stem from the electronics industry making use of monolithic integration processes in a batch fabrication manner. However, monolithic integration and thermo-mechanical treatment of SMA thin films are hardly compatible with each other. In order to avoid such incompatibilities, novel transfer bonding technologies are described, which offer a means to integrate all kinds of SMA materials on a chip without affecting their functionality.

“Modeling and Characterization of High Temperature Shape Memory Alloys”
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Shape memory alloys (SMAs) over the last three decades have found many applications, as actuators, sensors, for damping and biomedical implants. The effort over the last decade to develop actuators for use in elevated temperature environments (greater than 100°C) has led to the development of a new class of SMAs referred as high temperature shape memory alloys (HTSMAs). These alloys have transformation temperatures range from 100 to 1100°C, with high stress actuation capabilities. Several alloys were designed to reach these conditions, most of them produced by alloying binary NiTi with a third element such as Pt, Pd, Hf and Zr. The NiTiPd HTSMAs have gained significant interest due to their relatively high transformation temperatures, compared to NiTiHf and NiTiZr, and smaller cost, compared to NiTiPt. The high temperature actuation conditions
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However expose the HTSMAs to viscoplastic mechanisms, which affect their actuation performance. The appearance of creep during transformation induces a complex behavior, and requires the design of appropriate constitutive model, which accounts for both transformation and viscoplasticity, in order to predict the cyclic effect on the actuation strain.

The present work is focused on studying the cycling actuation behavior of HTSMAs undergoing simultaneous creep and transformation. For the thermomechanical testing, a high temperature test setup was assembled on a MTS frame with the capability to test samples at temperatures up to 600°C. Constant stress thermal cycling tests were conducted to establish the actuation characteristics and the phase diagram for the chosen HTSMA. Additionally, uniaxial and creep tests were conducted at different test temperatures to characterize the creep behavior of the alloy over the operational range.

In order to capture the HTSMAs behavior we introduce a thermodynamically based constitutive model for HTSMAs, where the appearance of viscoplastic mechanisms during transformation influences the cyclic response of the actuator performance. The model aims to capture the simultaneous rate independent transformation and the rate dependent viscoplastic behavior. Due to the cyclic response, two additional mechanisms are present and are accounted for: plasticity occurring during transformation and the accumulation of retained martensite. Based on previous models in conventional SMAs, a Gibbs free energy potential is defined, as with the appropriate evolution equations for forward, reverse transformation, plasticity occurring during transformation, retained martensite and viscoplasticity. The calibration of the proposed model is based on the uniaxial and creep tests, as well as fast load biased thermal cycling tests. In order to validate the model prediction capabilities, slow load biased thermal cycling tests are used, where creep interacts with transformation.

“Energetics of Transformation and Twinning”
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We are studying the GSFE (generalized stacking fault energy) and GPFE (generalized planar fault energy) behavior of the B2 (ordered cubic) structure. We are seeking to establish from first principles the energy barriers for onset of slip (GSFE) and for mechanical twinning (GPFE). The twinning systems can be rather complex involving both shear and shuffles. We study number of metastable positions and amplitude of the oscillations to understand the magnitude of the shear stress for twinning. We show simpler examples from fcc twinning energy barriers and how they are used to establish twinning stress from first principles. Similar ideas, involving energy barrier determination, apply for determining the transformation stress.
“New Observations on Transformation Hysteresis, Room Temperature Instabilities, and Twinning in Shape Memory Alloys”

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In this talk, we will present recent observations on few anomalous behaviors that were observed in several different shape memory alloys (SMAs) and the potential microstructural mechanisms responsible for these observations. These include: (a) reduction in measured transformation strain and hysteresis in isobaric heating-cooling experiments with increasing constant stress levels and in superelasticity experiments with increasing test temperature; (b) transformation memory effect upon thermal or mechanical cycling; (c) room temperature aging effect and room temperature recovery of irrecoverable transformation strain; and (d) unusual deformation twinning phenomenon in martensite which is completely reversible upon reverse transformation to austenite.

Reduction in transformation strain was attributed to the change in lattice constants of martensite and austenite differently under stress due to their elastic moduli mismatch leading to more compatible transforming phases. Such improvement in the compatibility also leads to reduction in transformation hysteresis with increasing stress levels or with temperature (due to the increase in the critical stress for martensitic transformation). The latter is true only if SMA is not prone to excessive transformation-induced plasticity, in other words if the material is strong.

Superelastic cycling of shape memory alloys (SMAs) usually results in a gradual reduction in critical stress to induce martensitic transformation (σ_{SM}) and stress hysteresis (Δσ), and an increase in irrecoverable strain (ε_{irr}). These changes are traditionally considered to be related to plasticity and therefore, permanent. However, we have found this not to be the case in some SMAs. Aging at room temperature following superelastic cycling produced gradual, but significant recovery in both σ_{SM} and Δσ, implying that room temperature aging is able to erase changes to the superelastic behavior accumulated during cycling. Furthermore, during cycling of a Ti-Nb SMA, growth in cumulative ε_{irr} abated after several hundred cycles, and was surprisingly followed by a slow depletion of the accumulated ε_{irr} with increasing cycle numbers. Both room temperature aging and cyclic recovery phenomena are believed to be caused by inherently diffusion-based mechanisms related to evolution of defect structure during the superelastic cycling process. However, it does not appear that a single mechanism is responsible for both behaviors.