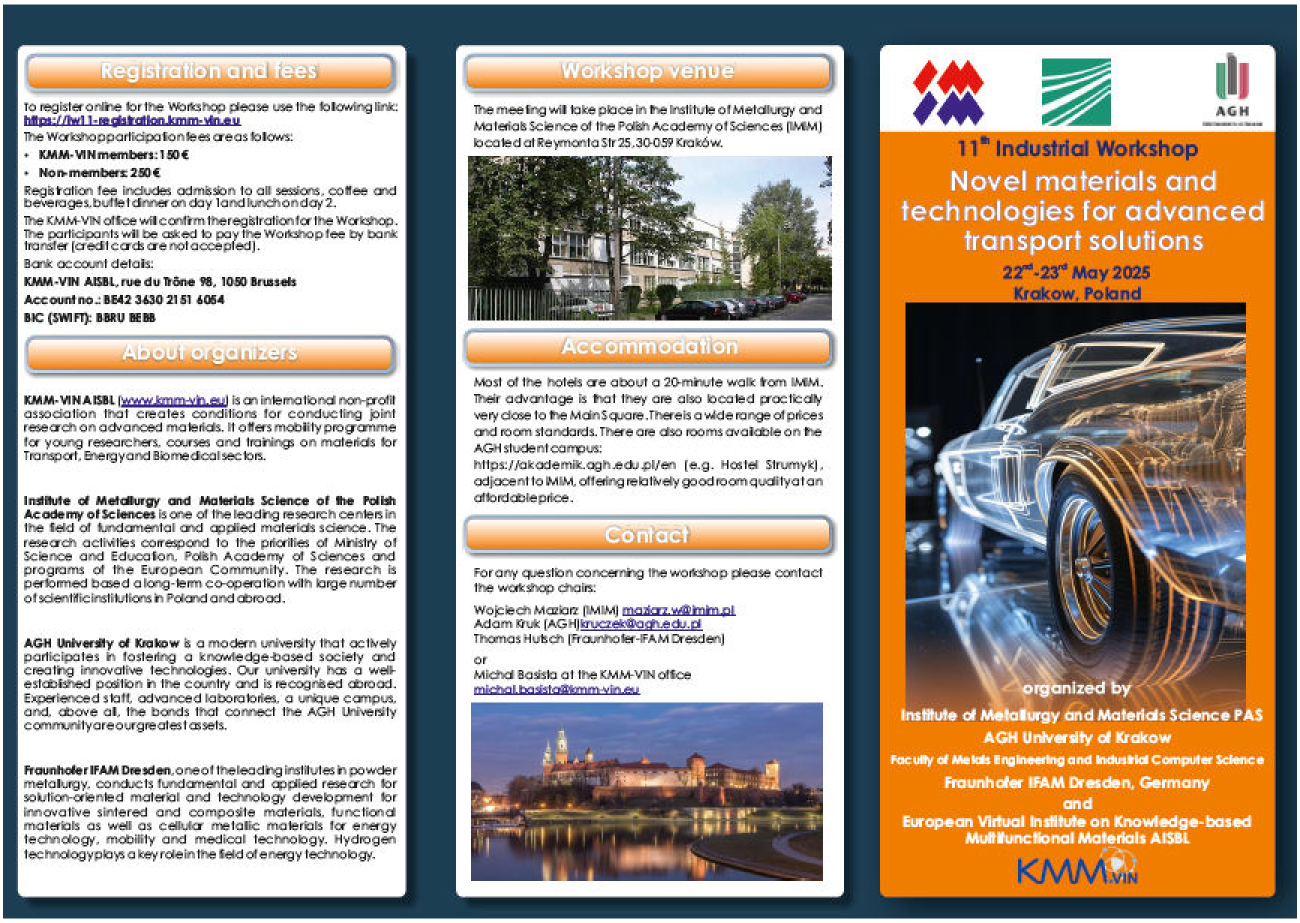
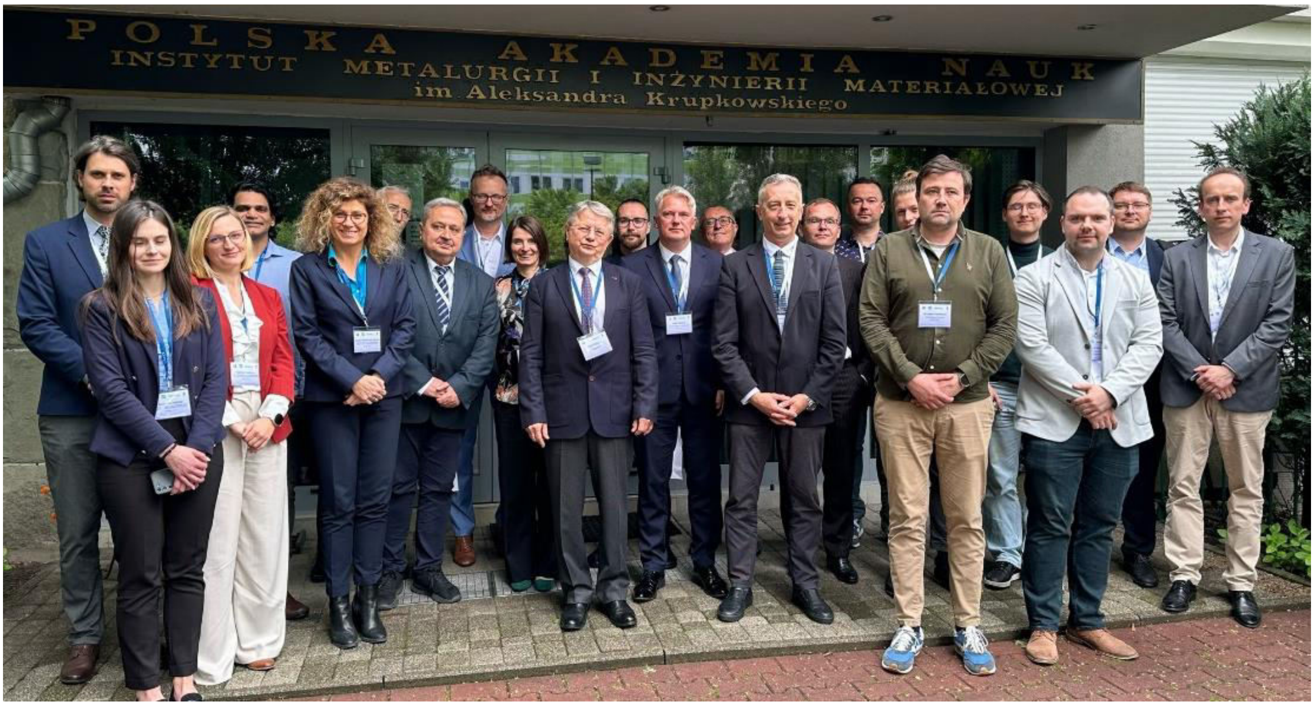
11th Industrial Workshop „Novel materials and technologies for advanced transport solutions", 22-23 maj 2025r, IMIM-PAN w Krakowie

W dniach 22-23 maja 2025 r. w IMIM-PAN odbyła się 11-ta edycja warsztatów ***11th Industrial Workshop „Novel materials and technologies for advanced transport solutions"*** zorganizowanych w ramach europejskiego instytutu wirtualnego European Virtual Institute on Knowledge-based Multifunctional Materials AISBL (KMM-VIN) z siedzibą w Brukseli. Tegoroczne warsztaty zostały zorganizowane przez trzy instytucje IMIM-PAN (Wojciech Maziarz), AGH Wydział Inżynierii Metali i Informatyki Przemysłowej (Adam Kruk) oraz Fraunhofer IFAM Dresden (Thomas Hutsch) w ramach działalności w grupie roboczej WG-1 Materials for Transport (KMM-VIN).



Oficjalna ulotka 11th Industrial Workshop „Novel materials and technologies for advanced transport solutions"

Głównym celem wartsztatów była prezentacja najnowszych trendów w rozwoju materiałów i technologii związanych z szeroko pojętym transportem. W warsztatach uczestniczyło 30-ciu naukowców zarówno z polskich jak i zagranicznych (Niemcy, Czechy, Słowacja, Wielka Brytania, Indie) instytucji naukowych i przemysłowych. Wśród nich znaleźli się przedstawiciele naukowców będących na każdym etapie kariery tj. doktoranci, doktorzy, doktorzy habilitowani i profesorowie.



Wspólne zdjęcie uczestników seminarium

W czasie warsztatów wygłoszono 6 referatów zapraszanych (keynote) oraz 11 wykładów regularnych uczestników. W pierwszym dniu spotkania dominowała tematyka związana z wysokowytrzymałymi materiałami na osnowie HEA, wysokowytrzymałymi stalami dla przemysłu samochodowego oraz stopami aluminium do zastosowań w układach elektrycznych przemysłu motoryzacyjnego. Drugą grupę tematyczną stanowiły technologie nanoszenia innowacyjnych warstw oraz materiały funkcjonalne z potencjalnymi zastosowaniami jako przełączniki, siłowniki, czujniki itp. W drugim dniu dominowała tematyka związana z materiałami kompozytowymi, niekonwencjonalnymi metodami łączenia różnego typu materiałów oraz zastosowania sztucznej inteligencji (AI) w analizie mikrostrukturalnej materiałów. Warsztaty okazały się doskonałą platformą łączącą zagadnienia związane z potrzebami nowoczesnego transportu z ofertą naukowców, co potwierdzały interesujące dyskusje podczas obrad.

11th KMM-VIN Industrial Workshop

Novel materials and technologies for advanced transport solutions

Programme and Abstracts

organized by

Institute of Metallurgy and Materials Science PAS

AGH University of Krakow
Faculty of Metals Engineering and Industrial Computer Science

Fraunhofer IFAM Dresden, Germany

and

European Virtual Institute on Knowledge-based Multifunctional Materials AISBL

22nd-23rd May 2025 Krakow, Poland

KMM.VIN

AGH
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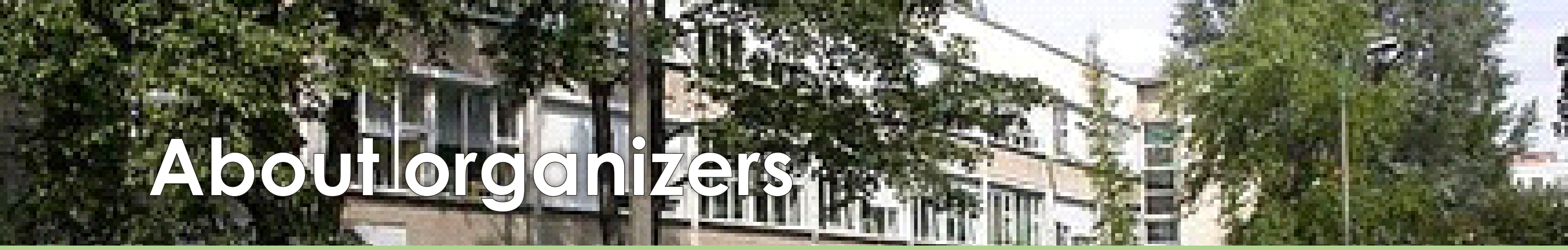


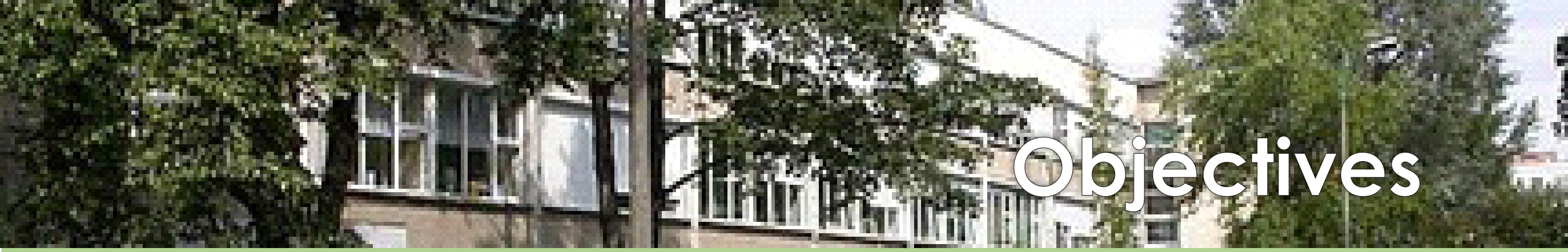
About organizers

KMM-VIN AISBL (www.kmm-vin.eu) is an international non-profit association that creates conditions for conducting joint research on advanced materials. It offers mobility programme for young researchers, courses and trainings on materials for Transport, Energy and Biomedical sectors.

Institute of Metallurgy and Materials Science of the Polish Academy of Sciences is one of the leading research centers in the field of fundamental and applied materials science. The research activities correspond to the priorities of Ministry of Science and Education, Polish Academy of Sciences and programs of the European Community. The research is performed based a long-term co-operation with large number of scientific institutions in Poland and abroad.

AGH University of Krakow is a modern university that actively participates in fostering a knowledge-based society and creating innovative technologies. Our university has a well-established position in the country and is recognised abroad. Experienced staff, advanced laboratories, a unique campus, and, above all, the bonds that connect the AGH University community are our greatest assets.

Fraunhofer IFAM Dresden, one of the leading institutes in powder metallurgy, conducts fundamental and applied research for solution-oriented material and technology development for innovative sintered and composite materials, functional materials as well as cellular metallic materials for energy technology, mobility and medical technology. Hydrogen technology plays a key role in the field of energy technology.



Objectives

The workshop will be held at the Institute of Metallurgy and Materials Science of the Polish Academy of Sciences (IMIM) on May 22-23, 2025 as a standard face to face event. This workshop will be the eleventh in the series of industrially oriented workshops organized by KMM-VIN in collaboration with leading research centres and industries. Presenting the most recent advances in material science and technology, the KMM-VIN workshops provide a unique opportunity for starting and/or intensifying the communication and cooperation between scientists and engineers, aiming at material-driven transformation of various industrial sectors.

The workshop will cover, but is not necessarily restricted to, the following topics:

- Light alloys, composites and modern steels in various industries
- Magnetic materials for electromobility
- Coatings for various applications
- Alternative joining of different property materials for a wide spectrum of industries
- Artificial intelligence-aided design of innovative structural and functional materials
- Novel advanced methods for materials characterisation

Workshop programme

22nd May 2025

Registration and coffee (12:00-13:15)
Introduction by:
Joanna Wojewoda-Budka, Director of IMIM PAN
Michał Basista, KMM-VIN CEO

Keynote lectures (13:30-15:30)

- **Robert Chulist**, AGH, *Precipitation-Driven Strengthening and Crystallography in FCC/BCC and BCC/FCC Soft Magnetic HEAs*.
- **Tomasz Tokarski**, AGH, *Applications of Aluminium Alloys in Conductors for the Automotive Industry.*
- **Adam Grajcar**, Silesian University of Technology, *Advanced Multiphase Steels for Automotive Applications.*

Coffee break (15:30 -16:00)

Oral presentations by Workshop participants (16:00-18:00)

Jan Dusza, *Microcantilever Testing of Dual-Phase Boride/Carbide High Entropy Ceramics*.

Peter Hannappel , *Predictive Thermodynamic Modeling of Metal Hydrides for Energy Applications.*

Milena Kowalska, *Magneto-Mechanical Response during Bending of Ni-Mn-Ga-Co-Cu Melt-Spun Ribbons.*

Izabella Kwiecień, *The Comprehensive Characterization of the Interfaces Formed due to the Nonequilibrium Conditions of Explosive Welding.*

Mateusz Włoczewski, *Nickel/CoCrFeMnNi electrochemical co-deposition with homogenisation annealing to obtain HEA layer.*

Marek Doubrava , *From Powder to Performance: Cold Spray Technology Boosting the Future of Automotive Industry.*

Dinner (19:30 -21:30)

23rd May 2025

Keynote lectures (9:00-11:00)

- **Ewa Olejnik**, Innerco S.A, *The Effect of the TiC Nanoparticle Pushing-Engulfment Phenomenon on the Mechanical and Functional Properties of in-situ Al-based Cast Composites in the Context of Transportation Application*.
- **Henryk Paul**, IMIM, *Phase Transformations in Explosively Welded Metallic Materials.*
- **Grzegorz Korpała**, MiViA, *Artificial Intelligence Powered Material Analysis.*

Coffee break (11:00 -11:30)

Oral presentations by Workshop participants (11:30-13:10)

Thomas Hutsch, *Copper-Diamond Composite with Complex Shape by GelCasting plus Spark Plasma Sintering.*

Dawid Hnatyk, *Improvement of Recycled Carbon Fibre Composite Behaviour through the Introduction of Natural Fibres*.

Anil A. Sequeira, *AlSi12/SiC Functionally Graded Composite for Modern Brake Disc: An Experimental Study of Thermal and Tribological Performance.*

Olena Poliarus, *New Composite Materials based on NiTi Intermetallic*.

Kamil Bochenek, Design and Characterization of a Cost-Effective HCCI/Al_2O_3 Composite.

Workshop summary and closing remarks (13:10 – 13:15)

Buffet lunch and networking (13:15 – 14:00)

Laboratory tour (IMIM PAN & AGH) (14:00-14:30)

Abstracts:
Keynote lectures

Precipitation-driven Strengthening and Crystallography in FCC/BCC and BCC/FCC Soft Magnetic HEAs

R. Chulist[1], W. Maziarz[2], A. Wójcik[1], N. Poręba[1], M. Czerny[2], M. Kowalczyk[3], N. Schell[4], M. Ziąbka[5], Ł. Hawełek[6]

[1]*Faculty of Metals Engineering and Industrial Computer Science, AGH University of Krakow*

[2]Institute of Metallurgy and Materials Science, Polish Academy of Sciences, Krakow

[3]Faculty of Materials Science and Engineering, Warsaw University of Technology, Warsaw

[4]Institute of Materials Physics, Helmholtz-Zentrum Hereon, Geesthacht, Germany

[5]Department of Ceramics and Refractories, Faculty of Materials Science and Ceramics, AGH University of Krakow

[6]Łukasiewicz Research Network—Institute of Non-Ferrous Metals, Gliwice

Email: rchulist@agh.edu.pl

The FeNiCoTaAl, FeNiCoAlTi, and CoFeAlCu bulk alloys and melt-spun ribbons have been investigated using high-energy synchrotron diffraction and high-resolution TEM. These alloy systems exhibit highly promising properties, achieving an optimal balance between magnetic and mechanical performance. A common characteristic among them is precipitation hardening, which significantly enhances both strength and ductility while simultaneously minimizing domain wall pinning. To refine the microstructure and produce metastable, disordered phases, the alloys undergo melt-spinning and hydrostatic extrusion—processes that involve rapid quenching and severe plastic deformation. Subsequent heat treatments initiate precipitation, promote chemical ordering, relieve internal stresses, and drive grain growth. This processing route enables precise control over the microstructure, chemical order, and precipitation behavior through systematic variation of heat treatment conditions. The results are further examined with respect to the crystallographic relationship between the matrix and precipitates, shedding light on the nucleation, growth, and coarsening of second-phase particles from a metastable, supersaturated solid solution. Consequently, a valuable design strategy for developing high-performance soft magnetic alloys is proposed.

Acknowledgment

Financial support of the National Science Centre, Poland (project no.2022/47/B/ST8/03298) is greatly acknowledged.

Applications of Aluminium Alloys in Conductors for the Automotive Industry

Tomasz Tokarski

Academic Centre for Materials and Nanotechnology, AGH University of Krakow

Email: tokarski@agh.edu.pl

As the automotive industry accelerates its shift toward electric mobility, aluminium and its alloys are playing an increasingly vital role in electrical conduction systems. Their favorable combination of good electrical conductivity, low weight, and cost-effectiveness makes them attractive alternatives to copper, especially in electric vehicles (EVs). Aluminium and its alloys are now commonly used in high-voltage busbars, battery interconnects, wiring harnesses, and cable bundles components where minimizing weight is critical for improving energy efficiency. While aluminium's electrical conductivity is slightly lower than that of copper, its significantly lower density allows for the use of larger cross-sections, achieving comparable electrical performance at reduced mass. In addition, aluminium's role in connectors especially crimped or welded joints has driven advancements in joining techniques and surface treatments to ensure durability and minimize contact resistance in demanding automotive environments. For applications where mechanical strength or fatigue performance is required, aluminium alloys must replace pure aluminium. However, alloying typically reduces electrical conductivity, presenting a key design trade-off. Modern aluminium alloys are thus engineered to achieve a balance between mechanical strength, formability, corrosion resistance, and electrical performance a challenge especially relevant in components that demand both high conductivity and structural integrity. The presentation will explore the role of aluminium in automotive electrical conduction systems, with a focus on currently available alloys and the challenges of designing materials that meet the conflicting demands of electrical and mechanical performance. Strategies for modern alloy development will be discussed, emphasizing the need for integrated solutions in the next generation vehicles.

Advanced Multiphase Steels for Automotive Applications

Adam Grajcar[1], Adam Skowronek[2,] Aleksandra Kozłowska[1]

[1]Department of Engineering Materials and Biomaterials, Faculty of Mechanical Engineering, Silesian University of Technology, Gliwice, Poland

[2]Faculty of Mechanical Engineering, Materials Research Laboratory, Silesian University of Technology, Gliwice, Poland

E-mail: adam.grajcar@polsl.pl

There have been a lot of new materials for advanced transport solutions in the last decade. One of them are advanced high strength steels (AHSSs), which offer a very wide range of mechanical and technological properties as well as operating performance. There are three generations of AHSSs, which can be produced as sheets, plates, forgings or long products. The 1st generation of AHSSs includes various groups of multiphase steels (dual phase, transformation induced plasticity, complex phase) containing different proportions of ferrite, bainite, martensite and retained austenite (RA). The 2nd generation of AHSSs involves manganese-based purely austenitic or almost austenitic alloys, whereas the 3rd generation of AHSSs comprises in majority medium-Mn (3-12 wt.% Mn) steels with multiphase microstructures and substantial amounts (15-50%) of RA. None of the advanced steels contain pearlite because carbon must be utilized here for other purposes.

This lecture is focused on microstructure-property relationships and manufacturing paths of cold-rolled and hot-rolled sheets products comprising of various fractions and morphologies of phases. The beneficial mechanical performance of the steels is possible due to interactions between soft and hard structural constituents and gradual strain-induced martensitic transformation improving both strength and ductility of the alloys. Some examples of new carbide-free bainitic steels or quenching and partitioning steels are characterized in detail to show the potential and complexity of structural interactions in these AHSSs.

The Effect of the TiC Nanoparticle Pushing-Engulfment Phenomenon on the Mechanical and Functional Properties of in-situ Al-based Cast Composites in the Context of Transportation Applications

Ewa Olejnik[1,2], Paweł Kurtyka[2], Agnieszka Czajka[1], Robert Chulist[3], Wojciech Maziarz[4]

[1]AGH University of Krakow, Faculty of Foundry Engineering, Krakow

[2]Innerco Sp. z o.o., Krakow

[3]AGH University of Krakow, Faculty of Metals Engineering and Industrial Computer Science, Krakow

[4]Institute of Metallurgy and Materials Science, Polish Academy of Sciences, Krakow

E-mail: eolejnik@agh.edu.pl

With increasing demands for fuel efficiency and reduced CO_2 emissions, lightweight yet high-strength structural materials are essential in the transportation sector. Aluminum matrix metal composites (AMMCs) reinforced with TiC particles present a promising combination of low weight and enhanced mechanical performance, making them highly suitable for automotive, rail, and aerospace applications.

This study investigates the influence of the pushing-engulfment behavior of TiC nanoparticles at the solidification front on their distribution within the aluminum matrix and the resulting mechanical properties. Three aluminum-based matrices were analyzed: Al 1000, Al-7%Si, and A356, each reinforced with 10 wt.% TiC. The results demonstrate that the matrix composition significantly affects particle size and distribution interdendritic in Al 1000, and intereutectic in Al-7%Si and A356—which directly impacts tensile strength enhancement.

The findings highlight that through controlled in-situ processing and appropriate alloy selection, the microstructure and mechanical behavior of Al-TiC composites can be optimized. These materials are particularly suitable for casting high-performance components such as engine blocks, cylinder heads, suspension arms, brake calipers, and structural brackets, where the combination of strength, wear resistance, and weight reduction is critical.

Phase Transformations in Explosively Welded Metallic Materials

H. Paul[1] R. Chulist[2], T. Tokarski[3] and S. Puchlerska[4]

[1]Institute of Metallurgy and Materials Science, Polish Academy of Sciences, Krakow

[2]AGH University of Krakow, Faculty of Metals Engineering and Industrial Computer Science, Krakow

[3] AGH University of Krakow, Academic Centre for Materials and Nanotechnology, Krakow

[4]AGH University of Krakow, Faculty of Non-Ferrous Metals, Krakow

Email: h.paul@imim.pl

New strategies in the development of metallic composites for advanced structural applications involve the synthesis of bulk materials. Multilayered systems with metallurgical bonding, consisting of alternating layers of two different metals, represent a notable example of such materials. Among the various methods for producing multilayered metallic composites, single-shot explosive welding (EXW) stands out as one of the most effective techniques. The aim of this research program was to develop and conduct a detailed structural analysis of multilayered composite materials based on combinations of metals that: (i) form, and (ii) do not form, intermetallic phases in the solid state. In both systems, local melting and rapid solidification near the interfaces resulted in regions composed of phases with highly varied chemical compositions and structures.

In the first group of metal combinations, this study investigates the transformations occurring at the bonding zones of AZ31/AA1050 multilayer plates. In the AZ31/AA1050 system, in addition to the two equilibrium phases, γ-$Mg_{17}Al_{12}$ and β-Mg_2Al_3, a significant fraction of the solidified melt regions consisted of non-equilibrium phases exhibiting amorphous or ultrafine-grained structures. During subsequent annealing, a pronounced growth of γ-$Mg_{17}Al_{12}$ and β-Mg_2Al_3 phases was observed near all interfaces from the early stages of heat treatment, while the phases within the pre-existing reaction regions systematically transformed into the β-Mg_2Al_3 phase. For annealing durations exceeding 10^3 hours, an intermediate ε-$Mg_{23}Al_{30}$ phase layer emerged between the β and γ phase layers.

In the second group of metal combinations, the layers adjacent to the interfaces exhibited complex and hierarchical microstructures. After EXW, the reaction zones consistently comprised a mixture of nanoparticles and fine dendrites of pure Cu and the reactive metals. Notably, no brittle intermetallic phases were observed near any of the interfaces in these composites. However, the microhardness of the solidified melt regions was two to three times higher than that of the annealed base materials. The large interface area per unit volume was found to enhance both the mechanical properties and the electromagnetic shielding effectiveness of the material, offering unique opportunities and challenges for technological applications.

Acknowledgements

The authors acknowledge the support of the National Science Centre (NCN) of Poland through projects no. 2021/41/B/ST5/04283 and 2023/51/B/ST11/02937.

Artificial Intelligence Powered Material Analysis

Grzegorz Korpała

MiViA GmbH, Institut für Metallformung, TU Bergakademie Freiberg, Germany

Email: Grzegorz.korpala@imf.tu-freiberg.de

The integration of Artificial Intelligence (AI) into material analysis has significantly advanced the field of metallography, enabling automated, precise, and comprehensive evaluation of microstructures in various materials. AI techniques, particularly Deep Convolutional Neural Networks (DCNNs), have demonstrated exceptional accuracy in classifying and segmenting microstructures in steel, nickel alloys, and other metals. By training on extensive datasets of metallographic images, these models achieve classification accuracies of up to 99.8%, effectively distinguishing complex microstructural patterns such as pearlite, martensite, and bainite. This level of accuracy is crucial for industries relying on rapid and reliable material characterization.

Beyond classification, AI-driven methods are now being employed for area-wide analysis of microstructural components. One prominent application involves the use of AI in evaluating the microstructural gradients within Jominy samples. By systematically analyzing microstructural variations along the length of the sample, AI systems can generate detailed maps of microstructural features, correlating them with heat treatment processes. This approach not only accelerates the analysis process but also provides valuable insights into the relationship between microstructural evolution and mechanical properties, such as hardness and tensile strength.

Moreover, the implementation of AI-powered microstructure analysis systems in industrial production environments has opened new avenues for real-time quality control. These systems employ machine learning algorithms to assess microstructural features directly on production lines, allowing for immediate identification of defects or deviations from expected microstructural patterns. By integrating such systems into manufacturing processes, companies can reduce inspection times, minimize material waste, and maintain consistent product quality.

Overall, AI-powered material analysis represents a transformative step forward in metallography, combining high precision, rapid data processing, and comprehensive analysis capabilities. This emerging technology not only enhances traditional methods but also introduces new approaches for understanding and optimizing material properties in various industrial applications.

Abstracts:
Oral sessions

Microcantilever Testing of Dual-Phase Boride/Carbide High Entropy Ceramics

Jan Dusza

Institute of Materials Research, Slovak Academy of Sciences, Košice, Slovak Republic

Email: jdusza@saske.sk

The fracture characteristics of recently developed dual phase high entropy boride/carbide ceramics were investigated applying micro-cantilever bending tests. Different processing routes have been applied for the preparation of the investigated systems, as reactive sintering and carbothermal reduction.

The microstructure and fracture characteristics were investigated using X-ray diffraction (XRD), scanning electron microscopy (SEM) in combination with electron back scattered diffraction (EBSD) and transmission electron microscopy (TEM). Atomic structure and local chemical disorder was determined by means of scanning transmission electron microscopy (STEM) in conjunction with energy dispersive X-ray spectroscopy (EDS). During micro-cantilever tests in bending deformation and fracture characteristics of individual grains and grain boundaries have been investigated. The bending strength of micro-cantilevers was strongly dependent on the character/size of the fracture origins.

Keywords: Microstructure, fracture, high entropy ceramics, microcantilever test

Acknowledgements

This research work has been supported by the Slovak Academy of Sciences (project: M-ERA.NET 3 DuplexCER).The present study was also supported by the Slovak Research and Development Agency (contract No. APVV-19-0497) and by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09101-03-V05-00009.

Predictive Thermodynamic Modeling of Metal Hydrides for Energy Application

P. Hannappel[1,2], G. Gu[3], M. Curnan[3], M. Palumbo[4], F. Heubner[2], M. Balcerzak[2,5], T. Weißgärber[1,2]

[1]TUD Dresden University of Technology, Faculty Mechanical Engineering, Institute of Materials Science,

Chair Powder Metallurgy, Dresden, Germany

[2]Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Dresden, Germany

[3]Korea Institute of Energy Technology, Department of Energy Engineering, Naju, Republic of Korea

[4] University of Turin, Department of Chemistry and NIS-INSTM, Turin, Italy

[5] Poznan University of Technology, Institute of Materials Science and Engineering, Poznań, Poland

Email: peter.hannappel@ifam-dd.fraunhofer.de

As the global energy landscape shifts toward sustainable solutions, hydrogen is emerging as a key enabler for clean energy systems. At Fraunhofer IFAM in Dresden, we contribute to this transformation with research spanning advanced materials for alkaline electrolysis, electrode development using porous foams and sintered structures, and reactor-scale simulations for optimized hydrogen storage and utilization. One area of particular interest is metal hydrides, which offer compact and reversible hydrogen storage, making them ideal for applications such as hydrogen compressors and purification systems.

A core challenge in developing and optimizing metal hydride materials is the lack of comprehensive experimental thermodynamic data—especially for multicomponent systems. To address this, our research uses Density Functional Theory (DFT) calculations to predict key thermodynamic quantities such as formation enthalpies and mixing energies. These theoretical results are then systematically integrated into the CALPHAD (CALculation of PHAse Diagrams) framework, allowing for the construction of predictive thermodynamic databases.

We designed a workflow that bridges ab initio simulations and macroscopic property prediction, capable of generating full Pressure-Composition-Isotherms (PCIs) without requiring experimental input.

This modeling framework opens new possibilities for accelerating the design of metal hydrides tailored to application-specific requirements. Beyond hydrogen storage alone, metal hydrides play a vital role in a wide range of hydrogen technologies - from thermal management in fuel cell systems, to hydrogen compression without moving parts, to gas purification by selective absorption and desorption. Predictive modeling of their properties thus represents a valuable tool for the development of next-generation hydrogen infrastructures.

Magneto-Mechanical Response during Bending of Ni-Mn-Ga-Co-Cu Melt-Spun Ribbons

M. Kowalska[1], P. Czaja[1,2], T. Czeppe[1], Ł. Rogal[1], M.J. Szczerba[1]

[1]Institute of Metallurgy and Materials Science, Polish Academy of Sciences, Krakow, Poland

[2]Department of Materials Science and Engineering, Stanford University, Stanford, USA

Email: kowalska.m@imim.pl

Ni-Mn-Ga-Co-Cu Heusler alloys are promising smart materials for magneto-mechanical applications due to their ability to undergo reversible magnetic field-induced bending (MFIB). This study investigates the effects of Co and Cu doping, melt-spinning velocity, and annealing on the structural and functional properties of $Ni_{50-x}Mn_{25}Ga_{25-x}Co_xCu_x$ (x = 1–6 at. %) ribbons. X-ray diffraction and differential scanning calorimetry revealed a phase evolution from $L2_1$ austenite to non-modulated 2M martensite with increasing dopant content, along with higher martensitic transformation temperatures and increased tetragonality. SEM analysis revealed that ribbons with lower doping levels (x = 1–3 at. %) displayed a solely austenitic microstructure, whereas those with higher Co and Cu content (x = 4–6 at. %) showed the presence of plate-like martensitic structures. Ni-Mn-Ga-Co-Cu melt-spun ribbons were annealed at temperatures between 373 K and 1173 K for 30 minutes, revealing two key effects on their mechanical behavior. The first, anneal hardening, occurred between 295 K and 773 K and was associated with crystal structure ordering and recovery. The second, anneal softening, was observed from 773 K to 1173 K and was linked to grain growth. Melt-spinning velocity significantly influenced ribbons' geometry and mechanical response; higher velocities produced thinner ribbons requiring lower bending loads. These ribbons also exhibited enhanced MFIB, with normalized deflection (ND) values rising from 0.07 to 0.47 as velocity increased from 5 to 20 m/s. The study establishes a clear relationship between processing conditions, microstructure, and magneto-mechanical performance. Notably, a strong inverse correlation was observed between mechanical bending load and magnetic-field-induced deflection. These findings demonstrate that melt-spun Ni-Mn-Ga-Co-Cu ribbons, when properly doped and processed, offer tunable magneto-mechanical behavior suitable for flexible actuator applications.

The Comprehensive Characterization of the Interfaces Formed due to the Nonequilibrium Conditions of Explosive Welding

I. Kwiecień[1], A. Bigos[1], M. Janusz-Skuza[1], Z. Szulc[2], J. Wojewoda-Budka[1]

[1]Institute of Metallurgy and Materials Science, Polish Academy of Sciences, Krakow, Poland

[2]High Energy Technologies Works "Explomet", Opole, Poland

Email: i.kwiecien@imim.pl

Innovative joining techniques, such as explosive welding (EXW), enable the production of hybrid materials for application in advanced transportation, due to combining lightweight with high-temperature and corrosion resistance and mechanical strength. EXW is a solid-state joining method. The parallel plate set-up consists of a flyer plate (FP) and a base plate (BP), separated by a spacer. The force of the explosion accelerates the FP toward the BP, causing a collision that creates a bond between them. EXW is a nonequilibrium process involving high pressure, localized heating, rapid cooling, and intense plastic deformation. The interface is often wavy or contains melted regions, revealing a strongly inhomogeneous chemical composition and even an amorphous structure.

This study focuses on the Ni/Al and Ni/Ti explosively welded interfaces. The Ni/Al bond consists of a continuous melted layer in the form of asymmetric waves, while the Ni/Ti interface shows a flat morphology with significantly fewer remelted areas. This can be explained by the smaller difference in melting points between Ni and Ti compared to Ni and Al. The extreme conditions of pressure and local high temperature led to the formation of intermetallic phases such as Al_3Ni, $Al3Ni_2$, and AlNi, as well as the metastable monoclinic Al_9Ni_2 phase at the Ni/Al interfaces. The local remelting zone at the Ni/Ti interface corresponds to the Ti and Ti_2Ni two-phase field in the equilibrium phase diagram. An additional annealing procedure resulted in the formation of parallel layers of Al_3Ni and Al_3Ni_2 at the Ni/Al interfaces, while for the Ni/Ti clad, the following phase sequence was identified: Ti /Ti_2Ni/TiNi/$TiNi_3$/ Ni.

Acknowledgments

The Institute of Metallurgy and Materials Science of the Polish Academy of Sciences (IMIM PAS) within the statutory work Z-5/2022 and the European Union from resources of the European Social Fund (Project No.WND-POWR.03.02.00-00-I043/16).

Nickel/CoCrFeMnNi Electrochemical Co-deposition with Homogenisation Annealing to obtain HEA Layer

Mateusz Włoczewski[1,2], Dariusz Jarząbek[2], Dariusz Oleszak[1]

[1]Faculty of Material Science and Engineering, Warsaw University of Technology, Warsaw
[2]Institute of Fundamental Technological Research, Polish Academy of Sciences, Warsaw

Email: mwlocz@ippt.pan.pl

High Entropy Alloys (HEA) are materials which have exceptional mechanical properties, high corrosion resistance and thermal stability. They often have properties that are not achievable with conventional materials. However, with excellent capabilities come high production prices. A potential way to reduce the price is to modify the surface of a cheaper material by production/deposition of HEA layer on it. Unfortunately, every known method of HEA coatings deposition have some disadvantages, such as high cost of equipment, limited preparing capabilities etc. The solution could be electrochemical deposition, method which is cheap and simple, but for multi elements HEA it is still a pioneering effort [1].

In this work we propose a simple and low-cost method to obtain HEA layer. The goal is to produce a coating using a hybrid combination of three methods – mechanical alloying, chemical electrodeposition and heat treatment. First step to obtain layer is preparing powder by mechanical alloying. Next step is co-electrodeposition, where to the chemical solution powder is added. After process, a coating composed of electrodeposited nickel and HEA powder is obtained. Finally the coating is homogenized. Optimization of the process will also be an important element in this work. This will be achieved by changing composition of HEA alloy prepared by mechanical alloying and by changing parameters of heat treatment. The applied combination of well-known methods and their appropriate optimization will significantly lower the costs of preparing HEA layers and simplify the process itself, expending the possibilities for HEA applications as protective or functional coatings.

[1] Popescu, A. M. J., Branzoi, F., Burada, M., Moreno, J. C., Anastasescu, M., Anasiei, I., Olaru, M. T., & Constantin, V. (2023). CoCrFeMnNi High-Entropy Alloy Thin Films Electrodeposited on Aluminum Support. Coatings, 13(6), https://doi.org/10.3390/coatings13060980

From Powder to Performance: Cold Spray Technology Boosting the Future of Automotive Industry

Marek Doubrava

Faculty of Mechanical Engineering, Institute of Materials Science and Engineering, Brno University of Technology, Czech Republic

Email: marek.doubrava@vutbr.cz

Cold Spray is a solid-state deposition technique in which metallic or composite powders are accelerated to supersonic velocity and consolidated by severe plastic deformation below their melting point. The absence of bulk melting eliminates solidification defects, preserves feed-stock microstructure, and enables dense, near-net-shape coatings and free-standing parts with negligible thermal distortion.

Automotive industry could easily benefit from the ability of joining dissimilar materials with high adhesion and cohesion strength and the inherent higher hardness of coating after deposition in comparison to the conventionally prepared material with identical chemical composition. The ability to repair and restore worn surfaces and the very insignificant heat input could increase effectivity of mold repair. Cold Spray technology is inherently sustainable, requiring only feedstock powder (metal, or ceramic/metal mixture), pure nitrogen and electricity.

Last but not least is the high quality of coating and its interface. Porosity below 0,5 % can be reached for broad spectrum of materials from light weight aluminum alloys, heavy weight copper and stainless steels to Inconel superalloys. Deposition rates reaching up to 10 kg h^{-1} render Cold Spray on the threshold of large-scale industrial deployment as a genuine additive-manufacturing technology.

Cold Spray technology is one of the youngest thermal spray technologies with significant benefits and inherent drawbacks. Ongoing research and development reveal new possibilities and applications, yet still we are in the beginning. The versatility, high deposition rate and negligible environmental impact renders CS to be a key element in numerous applications in automotive, aerospace, marine and military sectors.

Copper-Diamond Composite with Complex Shape by GelCasting plus Spark Plasma Sintering

Thomas Hutsch, Sebastian Riecker, James R. Siegenthaler, Matthias Mühle, Thomas Studnitzky, Johannes Trapp, Thomas Weißgärber

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM Dresden, Germany

Email: Thomas.Hutsch@ifam-dd.fraunhofer.de

The trend towards miniaturization is leading towards major challenges in the areas of electronic packaging such as cooling and temperature control and is thus leading to new challenges in terms of design and efficiency. To address these challenges, there is growing interest in complex-shaped customized packaging and cooling elements with enhanced thermal conductivity beyond conventional materials. Copper-diamond composites have been reported to possess the highest thermal conductivity up to 700 W/(m*K) @RT in flat geometries. Here we show our efforts to move copper-diamond composites with 60 vol.% diamond into the additive manufacturing space through a combination of gel casting and quasi-isostatic Spark Plasma Sintering (SPS) for complex thermal transfer devices. After green part manufacturing, the structures were subjected to debinding and presintering under hydrogen. A modified Spark Plasma Sintering process was used for densification and adjustment of the thermal conductivity, in which the structures were quasi-isostatically compacted. Sintered samples were measured to have thermal conductivities of 688 W/(m*K) @RT with a density of 5.1 g/cm³. This value is 1.7 times of pure copper (400 W/(m*K) @RT with a density of 8.89 g/cm³). Examples of possible complex shapes and the direct integration of alumina (as electrical isolating layer) will be given. Copper-diamond composites provide access to a new class of 3D cooling structures for direct cooling, which are greatly needed for effective heat dissipation in a wide range of applications, e.g. microelectronics, power modules, charging infrastructure and e-mobility. The developed routine can also be adapted to other high-thermal conductive materials

Improvement of Recycled Carbon Fibre Composite Behaviour through the Introduction of Natural Fibres

Dawid Hnatyk

University of Hertfordshire, College Lane, Hatfield, Hertfordshire, United Kingdom

Email: d.hnatyk@herts.ac.uk

The use of recycled carbon fibres (rCF) allows for reduction of emissions impacting energy and resource requirements. A major drawback of using rCF composites is the discontinuous nature of the fibres as this limits the performance and applications. The present investigation aimed to overcome some of these limitations by manufacturing hybrid composites by combining rCF and natural fibres (NF). One of the key observations was a significant change in the failure mode of hybrid samples under tensile loading, where the composite did not shatter but rather failed in a controlled manner. Initial results also showed an overall improvement in tensile strength. Similar performance was observed in flexural tests as well as impact tests. Research was focused on determining the most effective ply sequencing under different types of loading and understanding the effect of the ply sequence on the failure mechanisms. Composites with rCF core and NF skin proved to be the most optimal in bending and in tension, whereas other layups favoured one of the two conditions. During impact tests, the layup sequencing did not have a significant effect on the energy dissipation.

AlSi12/SiC Functionally Graded Composite for Modern Brake Disc: An Experimental Study of Thermal and Tribological Performance

A.A. Sequeira[1], T. Hutsch[2], J. Trapp[2], W. Weglewski[1], K. Bochenek[1], M. Basista[1]

[1]Institute of Fundamental Technological Research, Polish Academy of Sciences, Warsaw
[2]Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Dresden

Email : aseque@ippt.pan.pl

Substantially lightweight materials with high resistance to wear and capable of fast heat dissipation are essential for modern automotive brake disks. Functionally graded aluminum-matrix composites reinforced with ceramics have emerged as promising materials for such applications due to their low density, reduction of thermal residual stress generated during manufacturing, resistance to wear and thermal shocks [1]. Their inhomogeneous nature allows for macroscopic thermal and mechanical properties to vary across the volume, optimizing performance characteristics while ensuring efficient heat dissipation [2].

In this study, a stepwise graded aluminium alloy metal matrix (AlSi12) reinforced with silicon carbide (SiC) particles is selected in order to acquire graded combination of thermal, mechanical and tribological properties. Three-layered AlSi12-SiC composites with graded volume fractions of (10, 20, 30 vol.% SiC) are fabricated using two powder metallurgy techniques, namely hot pressing (HP) and spark plasma sintering (SPS). The thermal conductivity of the samples is evaluated using the flash method, the coefficient of thermal expansion is measured via dilatometry and the sliding wear behaviour is studied using a pin-on-disc configuration.

The study comprehensively examined the microstructure, with an analysis of the effects of porosity and ceramic reinforcement content on the thermal properties of FGM. Density measurements revealed that HP samples attained 98% of relative density, whereas SPS samples reached 95% of relative density. Neutron diffraction (ND) measurements indicated that thermal residual stresses within the graded layers decreased by approximately 10% compared to ungraded composites. The CTE measurements showed that the CTE of AlSi12/SiC composites are approximately 32% lower than that of the unreinforced aluminum alloy (AlSi12). Furthermore, the graded composites exhibited three times higher thermal conductivity at room temperature compared to grey cast iron, demonstrating their superior thermal efficiency. These findings highlight the industrial viability of functionally graded AlSi12-SiC composites for next-generation automotive brake disks. The enhanced thermal properties, combined with reduced residual stresses and good wear resistance, make them a compelling alternative to conventional materials.

Acknowledgement

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[1] A.A. Sequeira, W. Węglewski, K. Bochenek, Th. Hutsch, A. Jain, Th. Weissgärber, M. Basista; Metallurgical and Materials Transactions A, 2024, 55, 3706–3723.

[2] J. Maj, W. Węglewski, K. Bochenek, M. Basista; Metallurgical and Materials Transactions A, 2021, 52,4727–4736.

New Composite Materials based on NiTi Intermetallic

Olena Poliarus

Institute of Metallurgy and Materials Science, Polish Academy of Sciences, Krakow, Poland

Email: poliarus.o@imim.pl

A promising, and sometimes the only possible way to increase the exceptional characteristics of details is the use of composite materials based on metals and refractory compounds and protective coatings from them. Applying such coatings allows you to significantly improve the physical and mechanical characteristics of the surface layer, which most intensively perceives external loads and environmental influences. Oxides, carbides, borides and nitrides of transition metals are of greatest interest as a strengthening additives in composites.

Intermetallics of the Ni-Ti system with additives of refractory borides or nitrides are offered as corrosion-resistant components of metal matrix composites (MMCs). The unique characteristics of NiTi alloys, such as shape-memory behavior and superelasticity as well their biocompatibility, have made them very important in the biomedical fields (Orthodontic, Orthopedic applications, etc) [1-3]. But along with this, materials based on NiTi is also of great interest in the field of hydropower applications. The introduction of refractory compounds into the intermetallic matrix will significantly increase the hydroabrasive resistance of materials. In addition, such a combination of components will lead to a significant increase in the corrosion resistance of the developed materials and coatings in seawater.

Phase and structure formation of composite materials and coatings based on NiTi intermetallics with additives of refractory compounds was studied using SEM and TEM. The selection of the composition of new MMCs was justified in accordance with the results of contact interaction in the "refractory compounds-metal melt" systems.

[1] Chlanda, J. Witkowska, J. Morgiel, K. Nowińska, E. Choińska, W. Swieszkowski, T. Wierzchoń. Multi-scale characterization and biological evaluation of composite surface layers produced under glow discharge conditions on NiTi shape memory alloy for potential cardiological application, Micron, Vol. 114, (2018), pp 14-22.

[2] Innovations in Biomedical Engineering, Advances in Intelligent Systems and Computing, Vol. 526, (2016), 353 p.

[3] Vojtech D., Kubasek J., Novak P. Corrosion properties of the superelastic shape memory Ni-Ti alloy for medical implants. In: Manufacturing Technology, Vol. 13, No. 3, (2013), pp. 409-414. UJEP. Czech Republic.

Design and Characterization of a Cost-Effective HCCI/Al_2O_3 Composite

Kamil Bochenek

Institute of Fundamental Technological Research, Polish Academy of Sciences, Warsaw, Poland

Email: kboch@ippt.pan.pl

This study presents the development of a novel metal-matrix composite based on a high chromium cast iron (HCCI) reinforced with aluminum oxide (electrocorundum). An interesting feature of this HCCI+20wt% Al_2O_3 composite is the fact that the HCCI powder was obtained in our research laboratory from industrial waste shavings. By optimizing the powder milling process and consolidating the HCCI+20wt% Al_2O_3 powder blend in a hot press at 1175°C under a pressure of 20 MPa, an almost fully dense composite material was obtained (relative density of 99.84%).

The key material properties investigated for the HCCI+20%Al_2O_3 composite included fracture toughness under both quasi-static and dynamic loading conditions, as well as wear characteristics. A comprehensive wear testing program was conducted, including the ball-on-disc test, the flat-end pin linear abrasion test (Taber), and an abrasive blasting test. For comparative analysis, the performance of the base HCCI alloy and HCCI reinforced with uncoated zirconia toughened alumina (ZTA) was also evaluated.

The results from the Taber linear abrasive test and abrasive blasting demonstrated that the HCCI/Al_2O_3 composite exhibits superior wear resistance compared to the reference materials. The composite performed well in most tests, but showed increased wear in the ball-on-disc test, which is attributed to the unique microstructural characteristics of the reinforcing phase. Overall, this innovative HCCI/Al_2O_3 composite proves to be a cost-effective solution for the use of electrocorundum and industrial waste cast iron.

European Virtual Institute on Knowledge-based Multifunctional Materials (KMM-VIN AISBL)
rue du Trône 98, 1050 Brussels, Belgium
Phone: +32 2 213 4160, Fax: +32 2 +32 2 213 4169, email: office@kmm-vin.eu
http://www.kmm-vin.eu

KMM-VIN Branch Poland
Pawińskiego 5 B, 02-106 Warsaw, Poland
Phone: +48 22 122 8528, Fax: +32 2 213 4169