Metal Ceramic Composites Based on Preforms (NRT2-1)

Goal

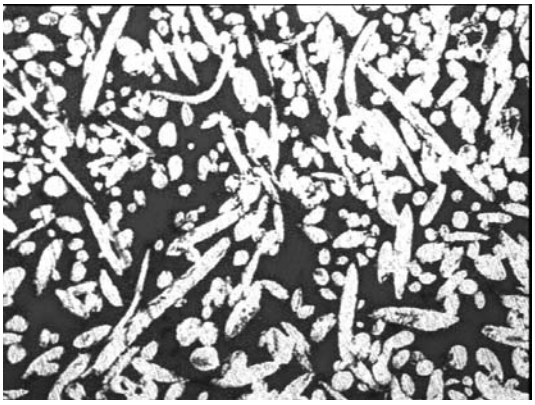
Metal ceramic composite of high thermal conductivity, high wear resistance, high fracture toughness, high strength for application from RT to 900 °C, - development, processing, determination and simulation of properties. This goal is approached by alumina copper composites with interpenetrating network microstructure.

State-of-the-art

Generally metal ceramic composites with interpenetrating network microstructure exhibit superior mechanical properties with regard to metal or ceramic matrix type composites. This is mainly due to weak metal ceramic interfaces. Alumina copper composites with interpenetrating microstructure, based on partially sintered ceramic bodies, were known with 15 – 25 vol.% Cu and metal ligament diameter of 0,15 – 0,75 µm. These composites were either prepared by gas pressure infiltration or by pressureless infiltration assisted by CuO. Fracture toughness values of up to 6.7 MPa√m had been obtained.

Progress in the project

Design and processing of new alumina copper composites extended available microstructures and metal-ceramic ratio considerably. New kinds of microstructures were achieved by preparation of porous ceramic preforms based on pyrolyzable pore forming agents as PU foams, felts of wool (s.fig.) and polypropylene and starch particles. Metal ligament diameter was increased up to 0,2 mm.



Processing is mainly based on gas pressure metal infiltration of porous ceramics. However, reactive, pressureless infiltration assisted by Ti was shown to be a feasible alternative. Experimental determination of elastic and fracture properties is currently under investigation. Simulation of these properties is investigated simultaneously based on modelling of the real microstructure via micro computer tomography. Biggest improvements are likely to be obtained with composites based on felt type performs.

Current work on processing, characterization, modelling and simulation will lead to a more thorough understanding of the relations between microstructure, properties and processing and thus to design of new composites to achieve desired properties.

Project partners

TU Darmstadt (Prof. Rödel, Gross), Polish Acad. Science Warsaw (Prof. Basista), Slovak Acad. Science Bratislava (Prof. Sladek), Slovak Acad. Science, Kosice (Prof. Dusza)

NRT 2-2 PARTMMC summary of results

Introduction:

The objective of PARTMMC was to develop a new route for the production of particulate reinforced aluminium and titanium matrix composites. The production route is based on the use of the SHS (self propagating high temperature synthesis) technology to obtain so called master compounds that are composed of a high percentage of ceramic particulates (up to 70-80 wt.%) embedded in a pure Ti or Al matrices. These compounds can be subsequently diluted into melt commercial alloys just before the casting step to produce components with a final reinforcement content of around 10%..

UH and Inasmet had some previous experience in the production of SHS ceramic powders and Inasmet had worked on titanium composites. Nevertheless the state of the art study did not identify any similar approach for the production of composites based on this concept.

The SHS process is a fast and low cost process suitable for the production of a large array of different ceramics and master compounds. The developed concept makes it possible to produce reinforced Ti and Al components with good reinforcement/matrix interphases, increased mechanical properties, low CTEs, wear resistance etc.

Main results:

PARTMMC has approached the processing, modelling, characterization and evaluation tasks of the development of the new reinforced titanium and aluminium concepts based on the SHS process.

In the case of titanium alloys pure Ti/TiB master compounds have been produced with success by SHS and added to Ti6Al4V alloy. UH and INASMET have contributed to the further optimization of the process up to obtain a material with 1.2 wt. % of TiB particles that complies with the high ductility and stiffness requirements established by EADS even though tensile strength values are so far lower than desired.

	E (GPa)	R_p 0,2(MPa)	R_m (MPa)	%
Developed Ti6Al4V/TiB 1.2% material	150	800	850	7.5
Requirements for plane applications	>125	>1100	>1250	>6
Requirements for helicopter application	>140	>1100	>1250	>5

The results of the aluminium reinforced materials are not yet available. Casting and forging reinforced alloy samples have been successfully produced presenting a sound microstructure and the modelling activities are finished. Wear resistance, fatigue and mechanical properties will be measured before the end of the project.

<u>Conclusion and Perspectives</u>

The new route for the production of titanium and aluminium composites has been validated through the production of MMC samples presenting good microstructures and good particle/matrix intephases.

The first results are promising but further work is needed to optimise the distribution of the particulates within the material and to increase the reinforcement content up to comply with the mechanical requirements established.

In the case of Ti reinforced alloys further work is needed to increase the TiB content and try to comply with the tensile strength and yield stress specifications. A compromise between the needed ductility and strength has to be found but the material presents reasonable chances to comply with the stringent requiremens.

In the case of Al reinforced alloys further work is required in order to avoid particulates agglomeration in the case of TiB_2 reinforcement and mixing step of the master compound and melt alloys through the study of the size and shape of the master compound powders and implementation of stirring technologies.

NRT2-3: Direct powder deposition (DPD) of MMC for aerospace components with tailored functionality

In aerospace and aeronautic applications components have to meet stringent performance requirements in combination with low weight and high reliability. At the same time they often have complex shapes and are needed only in moderate numbers so that tooling can represent a significant part of their total manufacturing cost. In principle, aluminium and titanium based metal matrix composites (MMC) produced by rapid manufacturing techniques could minimize tool costs while fulfilling all performance and reliability requirements. However, at the beginning of the project, rapid manufacturing techniques had been successfully applied to steel and titanium alloys only, and knowledge on the fabrication of aluminium or titanium based MMCs using such techniques was practically inexistent.

The aim of the project was thus to use direct powder deposition methods to produce complex shaped MMC parts and to assess the properties of the produced materials. For this purpose a task force consisting of one industry partner, four research institutes and a university institute was formed. An early evaluation of the advantages and drawbacks of existing rapid manufacturing techniques lead to the decision to use laser sintering as a manufacturing technique. For practical reasons, investigations had to be restricted to Al based MMCs. Further on it was decided to investigate whether the properties of the produced materials could be enhanced with short pulses of high electric current (so-called IECT, impulse electric current treatment). A door stop fitting was selected as a demonstrator component to be produced at the end of the project.

The major results of the project were the following:

- The feasibility of laser sintering aluminium alloys with and without ceramic particle reinforcement was demonstrated
- All produced Al-based MMCs suffered from excessive porosity exceeding 10 %
- The so-called "balling effect" was identified as the main reason for the residual porosity
- This effect seems to be caused by the oxide layer which the molten Al alloys form during laser sintering
- When SiC particles were used as a reinforcement, interfacial reactions between the Al alloys and the reinforcement during laser sintering were observed
- Aluminium matrix composite parts of a several inches size could be produced by laser sintering for the first time
- It was demonstrated that impulse electric current treatment has a positive effect on the mechanical properties of the laser sintered Al MMCs
- The mechanical properties of the laser sintered Al MMCs were still unsatisfactory

In conclusion, future developments to make laser sintering of high quality Al MMC parts for aeronautic applications feasible should first of all aim to avoid the detrimental balling effect which was always observed so far. This could be achieved by reducing the oxide layer of the aluminium melt formed during the process (e.g. by special alloying, changes in the process atmosphere etc). Alternatively, titanium alloys should be considered as a matrix metal for laser sintering MMC as less problems with interfacial reactions and better mechanical properties are expected.

NRT 2-4 NANOCERMET summary of results (A R Boccaccini)

Introduction

The main focus of basic research on nanostructured materials is, on one hand, to gain understanding of their intriguing physical and chemical properties (nanoscience), and, on the other hand, to utilize these novel nanomaterials in advanced (nano)technologies. The present task was designed to combine the expertise of key members of the KMM-NoE consortium in areas of processing, characterisation, modelling and application of nanomaterials in focussed research activities dealing with metal-ceramic nanomaterials, tackling both fundamental and application related issues. The ultimate aim of the task was to develop new multi-functional nanostructured composites in bulk form and as coatings, based on metal or ceramic matrices and the inclusion of dispersed nanoscale phases. Systems were selected for i) basic research on processing mechanisms and properties, and (ii) applications in technology and medicine. The following systems were selected: nanostructured ceramic coatings, nanostructured MMC coatings, bulk ceramic-metal nanocomposites, functional silica-metal nanoparticle composites and carbon nanotube (CNT) containing ceramics and glasses.

Main results

NANOCERMET has approached the processing, modelling and characterization tasks of the different systems mentioned above. For the evaluation for practical applications one system was specifically investigated: nanostructured ceramic coatings obtained by plasma spraying of ceramic nanoparticles for high friction and temperature resistant components (e.g. brake discs).

1) The production of nanostructured coatings using plasma spraying is especially interesting as only changes of the raw material would be required and no expensive new equipment investment would be necessary. WC-12%Co and Al_2O_3-13%TiO_2 nanostructured coatings were obtained and relevant properties were measured and compared with equivalent conventional coatings. The main microstructural differences were identified which explained the better tribological performance of nanostructured coatings. These nanostructured coatings were tested for brake applications. A brake car disc must be stable above 350°C, have high friction coefficient at high and low temperatures and have low wear rates. To optimise these conditions, nanostructured coatings were sprayed on cast iron brake discs and their performance assessed by measuring heat capacity and thermal conductivity, thermal modelling, wear and friction testing and testing using dynamometers (in service conditions).

2) Metal-coated ceramic nanoparticles and bulk composites and coatings based on ceramic-metal systems (Al_2O_3, ZrO_2, Cu, Ni-P, Ni-B) were also investigated. A new concept of ceramic nanocomposites was developed, based on metal coated ceramic nanoparticles by an autocatalytic chemical reduction process. This method offers the possibility of obtaining a thin, uniform nanometric layer of metal particles on the surface of the ceramic particles and consequently nanocomposites with uniform percolated structure were fabricated.

3) Carbon nanotubes (CNT) containing composites: CNT and zirconia nanopowder stabilised with Y_2O_3 and doped with TiO_2 were used for the first time to produce TiC/TZP nano-microcomposites containing TiC nanoparticles of the morphology taken from CNT. CNT/SiO_2 and CNT/TiO_2 nanocomposite coatings were also fabricated for the first time by a novel electrophoretic deposition technique. A modified colloidal processing was developed to fabricate monolithic SiO_2 matrix composites containing well dispersed CNT in concentrations up to 15wt%.

4) Ag, Au and Cu nanocluster/silica composites were developed as uniform and homogeneous layers on 10 cm diameter substrates. The available thickness for the metal nanocluster/ silica composites ranges from 25 nm to 2 microns, deposited with a uniformity of +- 2 nm. These nanocomposites exhibit antibacterial activity.

Conclusion and Perspectives

A new route for the production of WC-12%Co and Al_2O_3-13%TiO_2 nanostructured coatings based on plasma spraying was developed and the coatings were fully characterised and evaluated in a practical application (brake disk). The next step is to liaise with industrial partners for a full comparison of the novel coatings with conventional materials. The need for industrial input is also the next step in the development of Ag, Au and Cu nanocluster/silica composites. Major achievements in the processing of a variety of nanostructured composites, including novel CNT containing composites, as explained above, should now be completed with a comprehensive characterisation of the mechanical and functional properties as well as further modelling of the microstructure-property correlation. In addition, evaluation tasks of practical applications must be developed to assess opportunities for applications in fields as diverse as microelectronics, sensors, biomedical coatings and high temperature resistant components.