IMA 2002 Conference Proceedings

Industrial Minerals: a World of Possibilities

From quarry to high-tech

Under the Patronage of Mr Erkki Liikanen
Member of the European Commission
Responsible for Enterprise and the Information Society

Brussels, 6 June 2002

Venue: Charlemagne Building, European Commission

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Mr Erkki Liikanen

Member of the European Commission

Responsible for Enterprise and the Information Society

FOREWORD

On the day preceding the conference (5 June), IMA-Europe organised an inaugural dinner for the launch of its Awareness Campaign on Industrial Minerals. The dinner was held at the prestigious Solvay Library and was honoured by the presence of Mr Errki Liikanen, Member of the European Commission, and Mr Malcolm Harbour, Member of the European Parliament.

Mr Liikanen's speech is printed here below:

Ladies and Gentlemen,

Thank you for inviting me here this evening to address you on the eve of the IMA-Europe 2002 Conference of the International Minerals Association.

In my address this evening I plan to give you an overview of how I see the key enterprise and competitiveness challenges, and the link with sustainable development.

Enterprise and competitiveness

During the 1990s the European Union made substantial progress in achieving the Internal Market, and in finalising European Monetary Union. These are major achievements; the benefits from the single market have given a push to competitiveness and brought immense benefits to consumers also.

The introduction of the euro brings greater certainty to business activities. It brings also important advantages to the European consumers by increased competition and price transparency.

Economic growth, social cohesion and environmental protection must go hand in hand. This is the one of the Union's sustainable development strategy. Decision-makers must find a proper balance in what are sometimes competing policy objectives.

Improving competitiveness and productivity

As you are all aware, the European Heads of States and Governments, at the Lisbon Summit in March 2000, set the ambitious goal for Europe to become "the most competitive and dynamic knowledge-based economy in the world".

The competitiveness issue remains at the heart of the Commission's industrial and enterprise policy. Although growth and employment increased in the EU in the second half of the 1990s, Europe lost out to the US both in terms of competitiveness and living standards.

Our wealth, as measured by GDP per head, is less than two thirds of that in the US. This difference can be attributed to two factors: a lower level of employment and a lower average output per employed person in Europe.

In the short run, expanding employment can be an important source of economic growth. In the long run, productivity gains are the most important factor in raising standards of living.

The European Competitiveness Report 2002, which has recently been adopted by the Commission, points out that weaknesses in Europe's innovative performance and a slower introduction of new technologies are the origin of the gap with the US. This means we have to increase our efforts on all fronts to meet the goals set in Lisbon.

Information and Communication Technology

The importance of Information and Communication Technology (ICT) in economic growth and productivity performance is critical.

The strong growth and productivity performance in the US achieved during the 1990s went in parallel with increased investment and diffusion of ICT goods and services. In contrast, the weaker economic performance of EU Member States is in part linked to slowness in the adoption of these technologies.

As far as the minerals extraction and processing sector is concerned, a recent study commissioned by the Department of Trade and Industry in the UK shows a very limited penetration of ICT in this sector.

Among the key obstacles identified were :

- perceived high costs of a fully integrated Internet system, especially for smaller enterprises
- perceived limitation of staff resources
- a general conservative business culture
- lack of information about the benefits and difficulties in convincing staff internally and clients of the benefits.

These all are real challenges and they all must be that. The Commission addresses partly these challenges in its e-Europe action plan. The next step will be to stimulate, on the one hand services, applications and content, covering both on-line public services and e-business, while on the other to address the underlying broadband infrastructure and security matters.

These constitute the major objectives of the eEurope 2005 Action Plan which will be presented in the Seville European Council.

Innovation

Innovation also has played a crucial role in the acceleration of productivity growth in certain Member States and in the US.

Innovation is not limited to the invention of new products. The new technologies that are being developed at an increasing rate provide minerals processing companies with instruments that can help in innovating production and management processes. They improve quality and speed while reducing the costs. It is essential that your industry keeps innovation and modernisation as an integral part of its strategy.

I would like now to turn to another important issue dealt with in this year's competitiveness report, namely environmental performance of EU industries.
Recent evidence for the EU manufacturing sector illustrates how economic growth and environmental protection can advance in parallel.
Over the past twenty years, on most indicators, EU manufacturing has achieved a *de-coupling* of its environmental impact from its output. This has meant that while output has climbed, its actual impact on the environment has fallen.

This is an important finding which shows that the commonly held view in some quarters that manufacturing industry overall has been slow to bring about environmental improvement is simply untrue.

Better Regulation

Many minerals mining and processing companies are SMEs and as such are the focus of particular attention under Community policies. I will give one example of how we address their concerns.

Simplification and improving the quality of legislation is an essential objective for the purpose of reducing the burden on SMEs. As Enterprise Commissioner I have been a strong advocate of substantial improvement in this area.

I am pleased to be able to announce that the Commission approved today a major package of proposals on better regulation; including improved stakeholder consultation; and impact assessment. These will now be presented at the Seville European Council in June as the Commission's Action Plan for simplifying and improving the regulatory environment.

Specific sustainable development issues

Finally I would like to touch on a number of key issues affecting your industries which will arise over the coming months.

As you are aware, specific regulatory action in the field of mining and minerals processing has been announced in the Commission's "Communication on Promoting Sustainable Development in EU extractive industry". A number of actions are ongoing.

- The revision of the Seveso II directive will be adopted by the end of 2002. This will cover all major industrial risks related to the use and handling of dangerous substances.
- A draft directive on the Management of Mining Waste is intensively discussed with all stakeholders. The proposal will be presented to the European Parliament and to the Council by the end of 2002.
- A technical guidance document, the so-called "BREF on Management of Tailings and Waste Rock" is under preparation. It will be a milestone for the harmonisation of permits throughout the Union.
- As regards the New Chemicals Policy the concerns expressed by the industrial minerals industry about natural occurring substances are being studied at the moment. The aim is to seek solutions which avoid unnecessary burdens, while ensuring that we deal with real risks to health and the environment where they arise.

Encouraging voluntary efforts

We shall continue to encourage industry in its voluntary initiatives to address environmental problems. The "dust monitoring initiative" launched by the industrial minerals industries is a good example of a worthwhile initiative in this field.

Many enterprises in the minerals sector adhere to voluntary Environmental Management Systems (ISO or EMAS). Those schemes allow enterprises to meet more easily the legal requirements, but they also allow cost savings through better environmental performance.

Good progress is being made on the development of a set of "Sustainable Development Indicators for the non-energy extractive industry". I invite your enterprises to participate actively in this voluntary exercise. We will ensure that the results of the first campaign are made known as widely as possible.

The publication of a "Reference guide for good environmental practice in the European extractive industry", in co-operation between the Commission and the Minerals Industry, is another benchmark for Corporate Social and Environmental Responsibility. This initiative shows that this industry is able to put a sustainable development approach into practice.

Concluding Comments

Minerals extraction and processing industries have an important place in the EU economy. The conference tomorrow will provide a unique opportunity for the minerals industry to show also the important contribution to modern society.

I wish you a very successful Conference tomorrow.

WELCOME ADDRESS to the Conference

by the IMA President
Mr André J. Talmon

Today's conference marks the beginning of a new campaign called *"Essential, smart and beneficial Minerals - Your world is made of them"*, promoting **"Awareness"** in a new frame of mind for the European Industrial Minerals Industry.

In the past, this industry was happy to live hidden and be forgotten by the world around it.

However, the world around is changing, and we are expected to play a different game in the coming years. We have come to recognise that beyond economic and financial aspects, our future is impacted by our safe and responsible behaviour, as well as the good knowledge of who we are and what we do by our stakeholders: employees, communities around us, and the public in general.

"Awareness" seeks to make the world of industrial minerals, better known. The products, their end-uses, the production sites and technologies, the safe and responsible way in which we try to function.

Today's presentations have the ambitions to surprise you by showing some high-tech, avant-garde technology applications of some of the Industrial Minerals we represent.

The Directorate-General Enterprise has associated itself with this project. Not only did it encourage our initiative, but it also has taken direct steps to provide help and support in the organisation of this event. We are in this building today because they made it possible. To Mr. Erkki Liikanen for his patronage, as well as to all his staff that has been so helpful, goes our warmest expression of gratitude.

I do hope you'll find it a day well spent.

EUROPEAN COMMISSION
ENTERPRISE DIRECTORATE-GENERAL
Environmental aspects of enterprise policy, resource-based & specific industries
Steel, non-ferrous metals and other materials (Unit E.2)

Opening remarks

by Luis Montoya
Head of Unit

1 Introduction

Two years ago, IMA organised a Conference in Brussels on the *new communication culture*. The starting point was the particular relationship between the industrial minerals industry and local communities, but also the increasing number of legislative initiatives affecting this sector.

Looking at the actions taken in the meantime, this conference must be considered as a major success. The excellent relationship we have with the industrial minerals industry through its European federation, the Industrial Minerals Association (IMA-Europe) provides the best demonstration.

IMA is playing a *key role* in all activities held within the framework of the *Raw Materials Supply Group*, a consultative committee accompanying the Commission in its work in the area of the extractive industry. Bilaterally we try

to identify targets, which helps to reinforce the competitiveness of our industry, while considering the necessary protection of the environment and social impact. IMA participates in the SCHMOEI.

The minerals industry in Europe: vital role in our economy.

The extraction branches: output of 3 Mio t, value of € 50 billion, employs around 500.000 people. The main industries depending on these materials employ more_than 4 million people. Over 20 % of the European GDP is dependent in some form or other on the extractive industry.

Minerals are essential ingredients for our society. Each person in Europe consumes on average almost 400 tonnes of minerals during his life. Every citizen knows that minerals like sand, gravel and lime stone are used in buildings and infrastructure, but only few people realise that when they use paper, paints, glass, cosmetics, ceramics, plastics etc. in their daily life, they use in fact industrial minerals.

2 Actions

Reference to COM(265) Promoting SD in the EU non-energy extractive industry:

- First COM of Commission covering SD of a specific sector
- COM Strategy of SD only adopted one year later
- Today SD key priority in Commission's Work Programme

3 Challenges

Main challenge: Sustainable Development

3.1 Environment

Remains main focus

- Revision of the *Seveso II* directive will be adopted by the end of 2002. This will cover all major industrial risks related to the use and handling of dangerous substances.
- A *draft directive on the Management of Mining Waste* is intensively discussed with all stakeholders. The proposal will be presented to the European Parliament and to the Council by the end of 2002.
- A technical guidance document, the so-called *"BREF on Management of Tailings and Waste Rock*" is under preparation. It will be a milestone for the harmonisation of permits throughout the Union.

As regards the *New Chemicals Policy* the concerns expressed by the industrial minerals industry about natural occurring substances are being studied at the moment. It is our duty to find the appropriate solution to your problems, which are consistent with the overall objective, that is a high level of protection of human health and environment.

It is the Commission's role to ensure that these actions are necessary and proportional to the objectives of EHS. The *new Impact Assessment Scheme* presented by the Commission will help to maximise the benefits and to assure that the resulting costs are in balance.

The legislative actions will however have their limits in the protection of the Environment and Human health. They will not guarantee a *"zero accident level",* which should however be the aim of every responsible industry.

Therefore it will be necessary to developed actions that go beyond the legislative framework. The *Green Paper on CSR*, adopted last year illustrates that many companies do already take proactive approaches and invest in Sustainable Development. Public policies need to further these initiatives.

Voluntary Environmental Management Systems (ISO or EMAS). Clearly generates profits. Therefore it is astonishing to see that still a large number of enterprises do not adhere to these schemes. Perhaps need for specific sectorial adjustment?➔ *Action for IMA?*

Developing Best Practices. Example: "Reference guide for good environmental practice in the European extractive industry" (co-operation between DG ENTR / IMA) as a benchmark for Corporate Social Responsibility. It shows how practical and cost-effective approaches to environmental protection are implemented and it illustrates how this industry is able to put a sustainable development approach into practice.

3.2 Social pillar

Other voluntary initiatives in other fields than environment:

- IMA's voluntary initiative on dust monitoring
- The SDI developed together with DG ENTR refers in length to the social performance of our companies. It is important to show the results obtained both inside (lower accident rate, safety training programmes, other training) but also outside (open days etc)

3.3 Competitiveness

It goes without saying that economic/ productivity growth is at the centre of SD and the consolidation of the prosperity of the Union and its citizens.

The European Competitiveness report however notes that based on recent trends, EU productivity growth will be insufficient to attain the goals set by the Lisbon Strategy "to become the world's most competitive economy by 2010". Competitiveness is essential for the continuation of our economic model.

- GDP EU = 2/3 GDP US:
  - Lower investment in ICT (half of US); efforts need to be made mainly upgrading labour force skills (ref. Study DTI)
  - Recent underperformance of EU in production growth. Innovation played a crucial role.
- Research expenditure is a privileged indicator for innovation performance. Business research expenditure today annual increase EU 4,9 vs. US 8,2. Barcelona Council fixes target for total expenditure for R&D by 2010 3% of GDP!
- Reference to 6th Framework Programme (2002-2006):

Co-financing of Research projects will be available for SME's

Integrated projects: call for interest till June 2002.

NESMI is the Network on European Sustainable Mining & Processing Industries (www.nesmi.net). This new thematic network, an ambitious project under the 6th Framework Programme, involves different stakeholders (universities, industry, EC) and will ensure the necessary co-ordination/co-operation in RTD + provide information and knowledge transfer covering all mining issues.

4. Particular case of SMEs

Industrial minerals industry characterised by size of companies: most are SMEs that need particular attention.

Small and Medium sized enterprises are considered as central to SD in Europe. Small businesses play a crucial role in the development of competitiveness, innovation and employment.

A milestone has been reached with the endorsement of the EU Charter for SME in June 2000. This charter calls upon Member States and the Commission to take action to support and encourage small enterprises in ten key areas:

- Education and training for entrepreneurship
- Cheaper and faster start-up
- Better legislation and regulation
- Availability of skills
- Improving online access
- Getting more out of the Single Market
- Taxation and financial matters
- Strengthening the technological capacity of small enterprises
- Making use of successful e-business models and developing top-class small business support
- Developing stronger, more effective representation of small enterprises' interests at Union and national level.

The second annual implementation report, which reviews the progress made by Member States (MS) and the Commission shows the following key elements:

– Legislation is the heaviest burden for SMEs. Simplification and improved quality of legislation is necessary. Although most MS apply some kind of Regulatory Impact Assessment, more efforts remain to be done.

– A stronger political commitment is necessary to meet the objectives set by the Charter.

– We must listen more carefully to the needs of SMEs. Some good practices have been reported: Germany appointed a high federal representative for SMEs; the UK has opened an office in Brussels to represent national SMEs at EU level.

Generally, the Second Implementation report shows however encouraging results in the implementation of the Charter on SMEs.

Furthermore the Maribor Declaration signed in April 2002 extends the Charter for Small business to Candidate countries, which will be involved in all Enterprise Policy initiatives.

II. Introduction of the speakers of the afternoon session

This morning I started describing the relation between enterprise policy and minerals mining and processing industry. The focus was on challenges for this industry and its contribution to SD. I also addressed the role of public authorities to create appropriate framework conditions for the competitive development of industry. At the same time, public authorities need to assure a high level of environmental protection and to lay down and monitor the necessary rules for a high level of health & safety protection in and outside the companies.

In the meantime we listened to the very interesting presentations of high-tech applications for industrial minerals. Two presentations covered applications in the area of *transport* and where the Union provided an essential contribution for their development. The Gallileo project, which is known by all of you, could only be started after the Commission battled for years to convince the MS about its necessity and to provide the important financial funds. We got now the ingredients to appreciate the role public authorities can play to further, not only innovation, but also industrial development and related prosperity for European citizens. The Transrapid will also be a key element in the European transport policy.

Economic growth would be difficult to envisage without the progress made in the development of *special glass*, which plays an important role in the development of Innovation and Communication Tools.

ICT, as I mentioned this morning, are a key issue in the development of our economies. Not only the ICT sector contributes to the economic growth, but also and even more the using sectors. And its diffusion throughout the economy plays an important role in economic growth. I am glad to see this close relationship between ICT and Minerals. Having said this there will be no excuse for Industrial Minerals industries not to apply the highest rate of ICT.

The EU is the 2nd paper producer in the world. The US and Canada being the leader. Annual production of 75 Mio t = ¼ of world production; 1064 paper mills in the EU; 215 pulp mills.

Substantial contribution to SD:

– 45 % of fibres used for papermaking are recycled fibres = twice the rate of US

– pulp and paper 260.000 employees; capital intensive.

– Important consumer of energy: will benefit from liberalisation of energy market.

A Commission study on the pulp and paper industry underlines that most efforts for R&D and innovation were achieved, not in pulp and paper, but in related sectors. The presentation of Mr Malmivaara confirms the efforts of the supply industry. It will certainly be beneficial to get the paper industry closely associated and to combine efforts.

The 6 FP Research and Development will provide many opportunities and I invite you to have a fresh look at the opportunities offered. Knowing that the participation is becoming increasingly difficult under this new Framework Programme running between 2002-2006, I offer my to assist in identifying best opportunities to get involved.

Minerals and Space

By Dr Mario Lopriore

Technical Advisor to the Director of Technical and Operational Support of ESTEC, The Netherlands

(European Space Agency Technological Research Centre)

Today's world is an industrial world and industry has been associated from the very start with mining and minerals. Space industry is no exception and minerals have therefore found their way from quarry into space.

Not in large quantities though, and always after a considerable amount of transformation. Indeed space products are very sophisticated ones, always at the forefront of the technology because of the very high costs associated with the launching into space .Every kg into orbit cost up to 100.000 ! Such high costs enforce a constant evolution in the space products and this evolution can also be quite fast because of the competitive forces in the space market. Materials that constituted the only possible basis for a space product only a few years ago are challenged today by lighter and more performing alternatives. And new solutions are already been studied.

This presentation will cover a few examples of applications of minerals used for the different space products. These examples include both old and new applications. Each one of these, at the respective time of development, was enabled by the clever use of a mineral.

Man-made space has a number of facets: the first one is that of the satellites, the primary end product of the industrial chain, but also that of the launchers that provide access to space and of the space station: our inhabited satellite.

All these applications call for very performing solutions but also for well proven and reliable technologies and materials. Repairs in space are an expensive option that is seldom available!

It is evident that in the search for the most suitable implementation for a given mission, and given the variety of applications required, all the minerals that are on the agenda of this Conference are represented in space or have been used in one way or another to get the rest of the hardware up there. Time allowed will only consent the discussion of a few examples. Choice could not be done on the basis of ranking the "most represented" mineral in space. The minimal quantities - in absolute terms- currently used for space does not make this a sensible criterium. Neither is it reasonable to establish a ranking on the basis of the "most important" mineral, as every space product is always a compromise between performances and reliable alternatives of technologies, materials and techniques. This presentation is therefore based on an arbitrary selection of minerals in space, constrained by time and by the wish to present some less known facets of space hardware ...and of space minerals.

The best known example of minerals in space is Silica because of its use in glass for telescopes, and the best known telescope in space is the Hubble Space Telescope (HST). This telescope was injected into a low earth orbit still well above the earth atmosphere in order to improve the sharpness of the observations. HST is also well known for the major repair that was necessary to cope with the unexpected aberration of the main reflector.

This repair in space is possibly, still today, a world premiere for the complexity of the human intervention and, of course for its success story. Mirrors (reflectors) and the optical structures of a telescope have to maintain mechanical stability under severe thermal excursions. It is not easy to maintain a rigorous thermal control in all parts of a spacecraft under vacuum conditions when the sun shines.

Mechanical stability is achievable via use of SiC (silicon carbide) material. Even when the system concept allows cheaper structures for the reflector, e.g. via CFRP material, tight tolerances on the originating mould benefit from an implementation in glass ceramic. Silica is also used in other more sophisticated optic systems like SILEX (semiconductor laser intersatellite experiment) for its mirrors, lenses and structures as well as in all glass optical fibers of the telecom interconnect in the ISS (international space station). Associated with every optical application of Silica, there are the borates that ensure, case by case, specific improvement in the glass technical performances.

Silica is also used to produce Si (silicium) an element that is at the basis of all types of electronic components for use both in space and on the ground. One of these components, conceptually very simple, is the solar cell diode. This is used to generate voltage in space and power the system.
Solar Generators arrays are the well visible appendages of all satellites. These surfaces, deployed once the satellites are in orbit, extend for tenths of square meters and currently produce up to 10 KW. Satellites with up to 40 KW are planned for the future. A cover glass is

normally glued to the solar cell diodes to ensure protection against radiation by electrons and protons. Space is not an easy or benign environment !

A very typical space application of kaolin is in the mixes of fiberglass, ceramic and silica used in different configurations of the thermal shields of the vehicles that re-enter the atmosphere of the Earth or of Mars.

These shields can be of the ablative and non-ablative type. In the ablative ones , the thermal control is ensured via the overheating and loss of the material in the external layers of the shield. In the non-ablative ones the external shield heats up but can resist to temperatures in excess of 1200 degrees celsius and transmission of heath towards the rest of the vehicle is ensured via special insulations. Modern shields consist of inflatable structures with mixes of insulating layers of fiberglass and mylar.

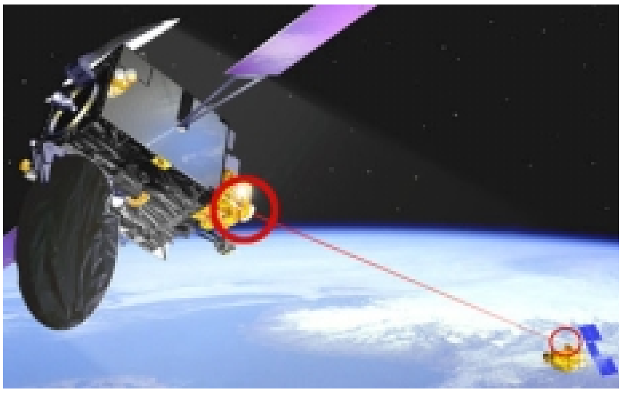
This much for minerals originated from the Earth. But the lack of gravity in space allows the production of high quality, large dimension crystals, for example the furnace of the Material Science Laboratory of the ISS (International Space Station) has been set up precisely to investigate this point.

From space it is possible to prospect for minerals on the Earth but also on the surface of the planet Mars. The ESA programme Mars Express, due for launch in 2003, not only will prospect the soil of Mars with a low frequency radar but also carry a Lander to prospect the Mars soil. This special spacecraft, named Beagle2 will carry five instruments and a specially conceived drill to extract a sample of Mars' soil and analyse it in situ. The results will then be transmitted up from Beagle2 to the mother spacecraft: Mars Express, and relayed back to Earth.

In the future the theme of this talk could well be: from a space quarry to Earth !

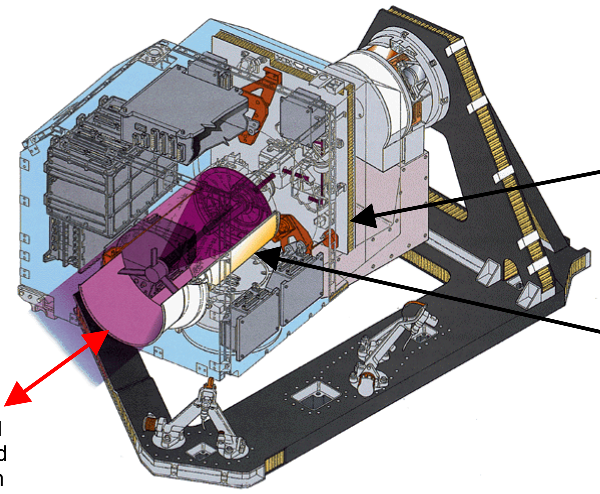
ESA's SILEX experiment
Semiconductor-laser Intersatellite Link Experiment

It comprises two complex optical terminals, one on Artemis (GEO) and the other on SPOT 4 (LEO)



Glass Optical elements on board include mirrors, lenses, filters, beamsplitters, polarizers, and fiber optics.

SILEX Terminal construction illustration



Special Glass: High tech made of minerals

By Dr.-Ing. Reiner Schumacher

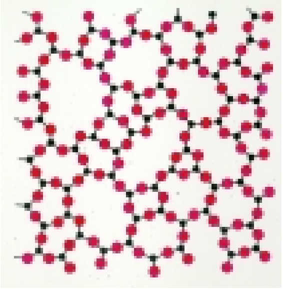
Representative to the EU, SCHOTT-ZEISS European Office, Zaventem

This presentation focuses on special glass. It is certainly of interest to producers to see what finally happens to their products, the minerals which serve as raw materials for the glass industry. So the aim is not only to show the final result but also to have a look at associated aspects and applications.

Generalities - an Introduction

Glass is an inevitable material in todays life, which serves as container for food, beverages or medicine, separates the inside of buildings and vehicles from the outside, while allowing free view.
It is mostly transparent and therefore unobtrusive, so we normally are not aware of its inner structure and what makes it so different from other inorganic solid materials like metals, ceramics and minerals. Its main raw material, silica sand, is available all over the world and nearly inexhaustible.

The microstructure of minerals and also metals is crystalline, where the elements form a more or less perfect lattice over thousands or millions of atomic distances, and ends up at the surface or the next grain boundary. The elementary cell is repeated again and again, and the chemical composition can be described by relatively simple formulas. Thermodynamically speaking the crystal is in a state of equilibrium.



For glass, things are different. Most glass types are based on silicon dioxide (SiO_2). In the crystal the silicon ion is surrounded by 4 oxygen ions, which form a perfect tetrahedron. Now when melted and cooled down not too slowly, it does not crystallize at a certain temperature, but gets more and more viscous until it seems to be completely rigid. The structure shows that locally the tetra-hedrons still exist, but on the long-term they are in a completely random order, which differentiates glass from crystals of similar composition.

As this is the structure we would expect from a snapshot of a liquid on molecular scale, we speak about a frozen liquid, which is not in a thermodynamic equilibrium. The open structure readily accepts additives in a wide range of compositions. As there are no grain boundaries, each piece of glass, however big, is a homogenous body, and, in the absence of tinting elements, it is completely transparent. Its mechanical behaviour shows no plasticity, which makes it rigid and brittle. The surface is mostly smooth like fire polished.

The pure silicon glass does not offer a wide range of applications and has melting temperatures beyond the normal technical range. Therefore beside the network builder SiO_2 we need fluxes to reduce the melting temperature. Suitable elements are for instance sodium and potassium.
This drastically reduces melting temperatures but has the unintended side-effect of raising the coefficient of thermal expansion (CTE) and, in particular, makes the glass water soluble. The chemical stability can be restored again by adding elements like calcium, magnesium, and others. Impurities like iron or other transition elements give the glass a greenish tint.
With such a composition we are already in the world of so called soda-lime glass, which is the basis for applications like windows and containers for food and beverages. Such glass has sufficient chemical stability to withstand normal agents and a low enough thermal expansion so as not to break at normal temperature conditions. The raw materials: sand, soda, limestone, dolomite and feldspar are available everywhere, and production costs are quite moderate.
Now everybody knows that pouring hot beverages into a normal drinking glass may lead to breakage and should be avoided. This brings us to the question, as to what we can do to make glass fit for special and higher requirements. Now we are at the point of transition to the world of special glass.
Special glass is based on the use of nearly all elements of the periodic system and in a wide range of compositions. Sometimes even the basic glass former, SiO_2, is substituted with other oxides. You can imagine that testing all compositions and figuring out the properties is a vast area of research, and at the beginning it was done more on a trial and error basis.
In the second half of the 19th century Otto Schott in Jena was the first to start a systematic scientific approach, which led to a number of new glass types for new applications. Even

today the process of screening to find new compositions is still going on.

Optical glasses

At first Abbe and Zeiss in Jena needed tailored optical glasses in order to drastically improve the quality of optical instruments. The most important requirements concerned:

- the refractive index, Symbol “n”, which describes how much a light beam is deflected when entering into an optical medium
- the Abbe-number “ν“, which says in principle how much the refractive index depends on the wave-length of the light

Beside this, optical glass should have a high transmission, which means a reduction of impurities to a much higher degree than in normal glass- which is a special requirement on the quality of the raw materials -, and the glass should be free of striae, inhomogeneities and other distortions, which depends on the melting process.
The effect of refraction is demonstrated by the interaction of an incident light beam with a prism. The angle of diffraction is greater for shorter wavelengths.
The most important instrument for optical designers is the Abbe diagram, where “n” is plotted against “ν”.
The most common element for raising the refractive index is lead, and, as the optician needs different glass types, at the early beginning there were two types of optical glass: crown (soda-lime silicate) labelled “K”, and the lead containing flint glass “F”. The refractive index as well as the Abbe-number varies with the lead content, in such a way that most glasses lie on a line or band in the Abbe diagram, and increasing lead content makes the glass very heavy.
In order to further improve the performance of optical instruments and to reduce weight, the optical designers want lighter glass types and some that lie to a greater or lesser extent apart from the main band in the diagram.
Therefore oxides of zinc, cadmium, rare earths, titanium, zirconium and many more are introduced as the “optical component”. Also silicon can be more or less substituted as glass former, but last but not least, the glass must be chemically stable and polishable.
Typically the introduction of every new element creates unintended side-effects that have to be compensated for by adding further elements. So the total system is very complex and it took decades to achieve today’s knowledge, which is stored in computers to facilitate the development of new compositions.

In order to demonstrate today’s quality of optical glass, two features should be considered: refractive index and transmission.

I-line glass is the present optical material for photo-lithography, the key-process in micro-chip manufacturing. The figures below demonstrate best, what can be achieved in optics. Even the measuring of the refractive index with such an accuracy requires special methods.

Transmission (iron content)	
Optical glass	< 1 ppm
Borosilicate float glass	~100 ppm
Soda-lime float glass	~1000 ppm

Refractive index, i-line glass :	
Homogeneity, one piece 220 mm Ø	$\pm 1x10^{-6}$
Variation within one lot	$\pm 2x10^{-5}$
Variation within production campaign	$\pm 2x10^{-4}$

The transmission can be characterized by the absence of limiting substances, the most common of which is iron. The iron content is mainly a question of raw materials, and it is clear that such high requirements cannot be met by natural raw materials straight from the quarry, but that there is a need for much treatment and processing. This is more and more standard practice now for all special glass raw materials.

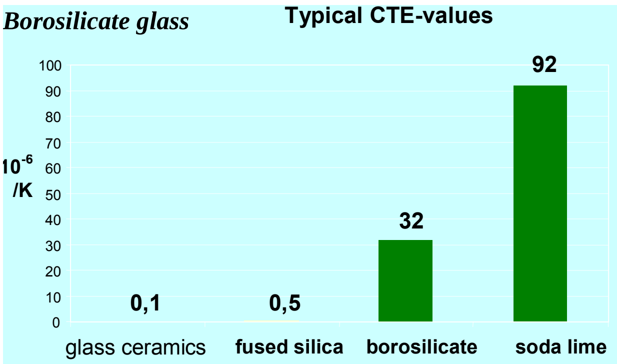
When describing applications of optical glass we can differentiate the more classical ones, like microscopes, with which things started, from those that are on the cutting edge of development. We may mention for instance, laser glass containing lanthanum as active laser material. Hundreds of large blocks of laser glass, based on phosphate instead of silicon, are the core components of the two big fusion experiments, one in the USA and the other in France, which will hopefully open the way to develop ways of meeting the energy demand of the next centuries. Due to the tremendously high laser energy, the glass pieces must be absolutely free of particles and inhomogeneities, in order to avoid destruction.

The telecommunication sector is the area where the future of optics is going to happen, and many experts are calling this century “the century of optics”, which is more and more replacing electronics.
The wafer-stepper for photo-lithography was already mentioned. Here the tendency is to go

to smaller wavelengths below the visible spectrum in order to obtain finer structures. The optical materials have to follow or better to be the pacemaker, and this question will be resumed later in the context of glass ceramics.
Tiny optical components with hundreds of coatings will drastically increase the capacity of internet communication.
Optical functions are integrated in small monolithic components and the signals from optical fibres are directly amplified, instead of first being demodulated into an electrical signal.

Borosilicate glasses

Otto Schott discovered the effect of boron when studying optical glasses. He found that the substitution of alkali as flux with boron would drastically reduce the CTE-value and so improve the resistance of glass to thermal shock, while allowing for higher SiO2 content, which improves the chemical stability.



The graph compares a typical borosilicate glass, the 3.3, which is standardized and still in use, with soda lime glass, fused silica and glass ceramics, which will be discussed later. As raw material we can use the mineral borax, as long as the limit for alkali is not exceeded.
The effect on the thermo shock resistance: even when tempered the borosilicate glass is superior to normal soda-lime glass.

Applications of borosilicate glass are cook and oven ware, x-ray tubes, laboratory glassware and pharmaceutical packaging.
Since about 10 years borosilicate-flat glass can be produced in float quality, and serves mainly for fire protection in buildings. It's temperature resistance is so high that chancellor Schröder can be confident of not being injured by the flame on the other side of the glass pane.

Displays

Glass for **C**athode **R**ay **T**ubes (CRT) is a high volume product in special glass and constitutes more than 50% in Europe. The funnel contains lead as specific constituent, which absorbs the x-rays that are generated by the electron gun of the tube, and so protects the health of human beings.
For the panel the x-ray shielding is accomplished by barium, and the strontium stabilises and helps prevent browning. The neutral grey colour is an essential feature of the picture tubes contrast and is accomplished by adding some cobalt and manganese.
Despite the trend of substitution in the monitor market for TV sets the performance of CRT's is still superior. In the meantime even full flat solutions are feasible, which is a high challenge for tube design and glass manufacturing.

Nevertheless, flat panel displays are the system of the future, and there is also special glass involved.
The thickness of the glass sheets is quite low, typically less than 2 mm down to 50 microns as depicted, and there are special requirements concerning the surface quality. The glass must be free of alkali and withstand high temperatures and have a low CTE, and the surface must be completely free of particles. The preferred composition is in the alumino-silicate area with boron as flux. The forming operation is a special drawing process or in future a micro-float, while the processing requires clean room conditions, which is quite unusual for the glass industry.
A new idea for surface light sources and displays is based on the use of organic light emitting diodes, which are expected to display important advantages, like flexibility, low power consumption, colours and viewing angle. This application is still in the research stage and supported by the European Commission.

Glass ceramics

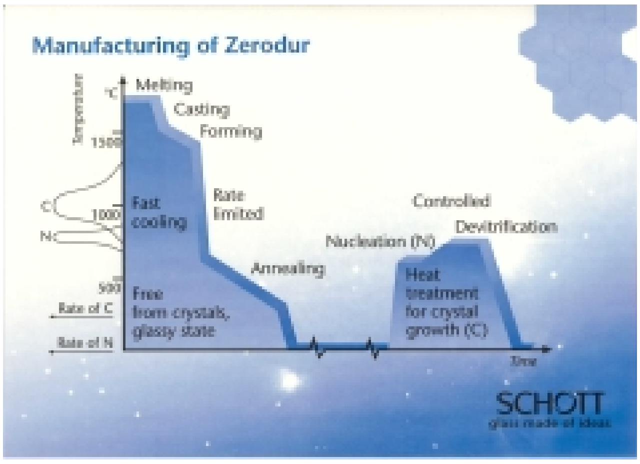
The material group of glass ceramics of low CTE type can be considered as the most spectacular success story of special glass.
Crystals, the elements of ceramics, is something that, in glass technology, normally appears under the category of defects. It can be either a residue of the minerals in the raw material, which has not completely been melted, or something that grows in dead corners of the melting tank. Anyway crystals mostly lead to rejects, when it gets into the product. Glassmakers don't like them at all.

But now we are dealing with crystals which are deliberately generated in the glass matrix. Glass-ceramics means crystals which are embedded into a glass matrix, and, of several

types presently known, I will concentrate on the low expansion type, also called high-quartz solid solution. The chemical formula is depicted on the chart (Li_2O-Al_2O_3-2 SiO_2). To a certain extent the substitution of the three basic constituents by other oxides is possible. The graph gives an impression of the microstructure of such crystals. You can see the tetrahedrons, where the silicon-ion is sitting in the centre.
Now in the early 50s it was discovered that these crystals display a negative coefficient of expansion, what means that they contract instead of expand when heated. It has also been found that such crystals can be generated in a glass of suitable composition and in a very controlled way by a specific heat treatment, the ceraming, when some nucleating agents like TiO_2 are present.

It is obvious, that such an observation opens up new areas of materials applications, and since about 1960 a lot of research has been started all over the world. The guiding idea was that crystals with negative CTI embedded in a glass matrix with positive CTE could result in zero expansion of the whole system. While the parent glass displays a CTE in the area of borosilicate glasses, the resulting composite is in fact practically a zero expansion material.

The ceraming process can be controlled in such a way that the crystal size remains below the wavelengths of light (typically ~50 nm) to keep the glass transparent or translucent.
Typically the crystals have a 70 – 80% share of the volume while numbering around $10^{16}/cm^3$.



The manufacturing of glass ceramics is a two step process; the first part is basically similar to conventional melting and forming according to the desired shape. In detail, however, carefully modified conditions concerning temperatures, materials and set-up are necessary to achieve satisfactory results.

The graph depicts the temperature against time. The essential fact in this context is that nucleation (N) and the crystal growth (C) take place within different temperature ranges, which have to be passed quickly during the forming process. The conversion into glass ceramics happens in the second step, the *ceraming*. There the material is at first heated to the temperature of nucleation, and then to the temperature of crystal growth. Depending on the material thickness the ceraming can last between minutes and months.

In the early stages, product ideas for glass ceramic applications mainly centred around cookware, but in the late 60s it was proposed to use it as substrate material for big telescope mirror blanks. A special composition under the brand name Zerodur® was developed, which is optimised for the temperature range –30 to +70 °C and meets the essential requirements of astronomers.
At the same time the technology for big castings of several metres in diameter had to be developed, and the first mirror blank was produced in 1973-1975. The final diameter was 3.6 m and in 1984 it has been installed on the Calar Alto in Spain.
According to the requirement of the astronomers, the mirrors for further telescopes had to be even bigger, around 8m and 25 tons for the ESO project on the mount Paranal in Chile. As the final shape of the blanks is curved and the major part of the blank usually has to be removed by machining, such big mirrors would exceed the size, which is technically and economically feasible. Therefore a spin casting process was developed, which allows a blank size much closer to the final shape of a meniscus, 8.2 m in diameter and 167 mm thick, to be achieved.
Four of these mirrors have in the meantime been installed and put in operation, after several years of processing.
Another way to achieve mirror sizes even beyond 8 m is with segmented mirrors, which consist of smaller hexagonal mirrors, separately supported by actuators in order to compensate for any deformation by gravity. There are several projects finished or in the pipeline, one of which is GranTeCan.
The Gran Telescopio Canarias has a main mirror of 10m consisting of 36 segments of 1.9 m. The segments have already been delivered and "first light" for the telescope is scheduled for 2003. It will be furnished with an active optics system, which means that the focus is continuously optimised by actuators under the individual segments. This project is funded by the European Union.

For space based telescopes the weight of the system is the limiting factor. Therefore methods have been developed to reduce the weight, for instance by machining, or welding together thin glass ceramic sheets, which is not a trivial problem.
X-ray telescopes like the CHANDRA Project use nested conic tubes of glass ceramics. The deflection of x-rays is here based on the principle of “grazing incidence reflection” at the inner, coated surface of the tubes. The system was launched in 1998.
As a kind of by-product, the Zerodur® glass ceramic has found a lot of applications in metrology, where dimensional stability is a must. A standard for precision measuring systems in the automotive industry is depicted, as well as the latest big project, the Zeiss laser gyroscope to detect finest deviations in the earth’s rotation .
In parallel to the astronomical and industrial applications, more commercial applications for glass ceramics have also been developed.

Today black or white cooking surfaces dominate the market for hob tops, and flat or bent sheets of transparent glass ceramics serve as windows of open fireplaces. In this case, the composition of the material and the processing parameters have been optimised for a temperature range of 20-700 °C, while the basic properties are the same.
Recent developments are in projection systems, for so-called beamers, where glass ceramics withstand high temperatures and keep their dimensional stability.
As already mentioned, wafer steppers are the core equipment in manufacturing microchips, and according to Moore’s law the size of structures is continuously decreasing. The latest development, - at the moment not much more than ideas and laboratory results, but hopefully industrial practice at the end of the decade, - is the Extreme Ultra Violet (EUV) lithography. At the foreseen wavelength of 13 nm refractive optics will not work any more. Similar to x-ray astronomy, the solution is reflective optics with grazing incidence, and glass ceramics will be a preferred material.

Conclusions

Before concluding, a general word on the question of lead should be said. Today this material has a bad image, especially at the Commission. New legislation, like for packaging, automotive and electronic waste, stipulates far-reaching restrictions on the use of lead. On the other side, as shown, and there are many more examples, lead has a lot of benefits for special glass, which explains why it has been introduced into the glass to such a large extent.
Before legal restrictions had been discussed, the industry had already invested a lot of effort and money to find substitutes for lead, for example in optics, where nearly the whole standard catalogue has been revised. In the end, however, some applications will remain, where it would seem that we cannot find a suitable replacement, however the quantities involved are negligible. In those cases, a little more flexibility would be desirable, in order to find a better balance between ecological benefits and the technological and economical consequences.

This presentation has tried to show how many applications there are for special glass in our high tech society, where sometimes we are not aware of them. Although, due to the high requirements, many raw materials today come from chemical plants, in the end it’s all made from minerals.

Silica applications: the example of the Transrapid - the high-speed magnetic levitation train

by Dr.-Ing. Ralph Contag

Director Investment and Facilities, ThyssenKrupp Transrapid GmbH, Germany

Introduction

The high speed maglev transportation system Transrapid is the first system to use levitation, guidance, propulsion and braking contactless technology without wear or tear.

The functions are performed by electric and electronic means, realized in a redundant structure of autonomous modular units. Unlike cars or railroads, the maglev system's motor is located not in the vehicle but in the guideway. The long-stator linear motor functions like a conventional rotating electric motor whose stator has been cut up and extended. As a result, it produces a traveling magnetic field by which the vehicle is drawn through its support magnets synchronously and without contact.

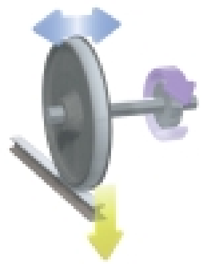
The long-stator motor integrated in the guideway consists of two main components: stator packs, having a length of 1m, and the motor winding realized by 3 bended cables, which are mounted into the slots of the stator packs. Each stator pack consists of 360 sheets, 3 attachment hangers for mounting to the guideway structure, and a coating to protect the electric sheets against corrosive effects from the environment.

As stator packs can not be exchanges during current operation of the system, the stator packs must have the same lifetime as the guideway girders. In combination with the epoxy-resin system, ***a Silica application*** contributes essentially to meet this requirement. The stator packs are produced under vacuum conditions by an automatic pressure gelation process. This special coating technology guarantees a life-long protection and contributes to the favorable features of the Transrapid System.

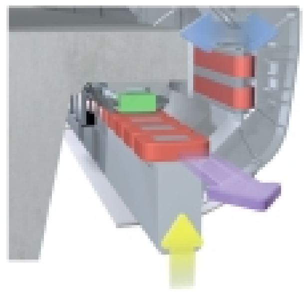
TRANSRAPID – Super High-Speed Trackbound Passenger Transportation

The superspeed maglev system Transrapid is an innovative track-bound transportation system for passenger and high-value cargo traffic at speeds between 300 to 500 km/h. It is the first fundamental innovation in railroad technology since the construction of the first railroad more than a hundred years ago.

The non-contact technology of the superspeed maglev system Transrapid - electronics are used instead of mechanical components - overcomes for the first time the technical and economic limitations of wheel-on-rail technology.



Wheel-on-rail



Electromagnetic levitation

The superspeed maglev system has neither wheels nor axles nor gearing. It does not roll – it hovers without touching the guideway, with no friction nor wear. Electronics replace mechanical parts.

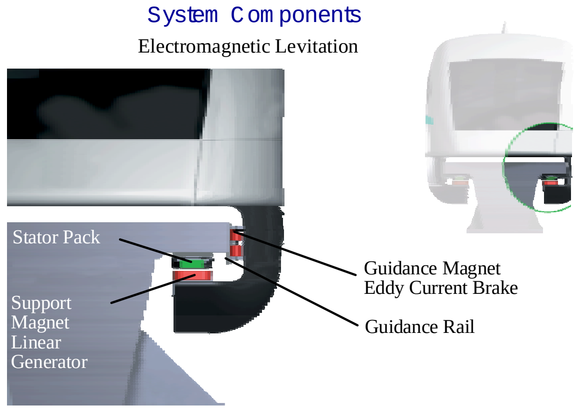
The functions of wheel-on- rail, i.e. support and guidance, propulsion and braking, are taken over by an electromagnetic levitation and propulsion system. The Transrapid system works completely contact free.

A highly reliable, fully redundant electronic control system ensures that the vehicle hovers at an average distance of about 10 millimeters from ist guideway.

The distance between the top of the guideway and the underside of the vehicle during levitation is 150 millimeters, enabling the maglev vehicle to hover over objects or a layer of snow.

The levitation system, i.e. support and guidance, is based on the attractive forces between the electromagnets in the vehicle, and the so-called stator packs and side guidance rails in the guideway.

In order to make the vehicle hover, the levitation magnets pull it toward the stator packs from below and the guidance magnets pull it to the side towards the guidance rails.



The support and guidance magnets are arranged on both sides along the entire length of the vehicle.

Basically it is really that simple - so simple that the invention is almost 70 years old - Hermann Kemper received the patent for the the magnetic levitation of trains by 1934!

The reason why it took so many years to form it into a reliable, useful application are the very heavy demands on the control system, which is only possible to realize by the use of high-performance computers.

Passenger and vehicle safety is clearly enhanced by the technical concept of the magnetic levitation train. Transrapid vehicles virtually cannot derail, since they wrap around the guideway.

The complete absence of crossing in the track routing prevents accidents with other means of transportation. The superspeed maglev system is propelled and braked by means of a long-stator linear motor.

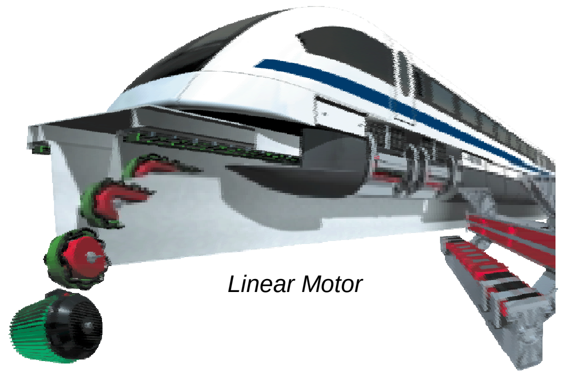
The method by which the linear motor functions can be derived from a conventional electric motor - the stator is cut open, stretched, and laid out along the entire length of the guideway on both sides.

Instead of a rotary magnetic field , the motor generates an electromagnetic travelling field. The support magnets in the vehicle function as the rotor of the electric motor. Alternating current in the cable windings generates an electromagnetic wandering field by which the train is pulled along without contact. By changing the intensity of the current, the thrust and speed of the train can be continuously varied - from standstill to full operating speed. The motor can also be used as a generator which then brakes the train.

In contrast to the conventional railroad, the primary propulsion component of the Transrapid maglev system - the stator packs with three-phase motor winding - are not installed in the vehicle but in the guideway, which means that the vehicle does not need to „carry" the motor with it. Furthermore only the power which really is needed is installed in the guideway – more at ascending slopes or accelaration tracks, less at curves or stations.

The longstator linear motor in the guideway is divided into individual motor sections which are only supplied with power as the vehicle passes. The support and guidance system is supplied with energy without contact via the linear generators integrated into the support magnets. No overhead wires are required for the Transrapid.

In the event of a power failure, energy is supplied from on-board batteries which are charged by the linear generators during travel. Classic batteries are still used but the development of hydrogen energy cells will replace these soon since batteries are very heavy. The Transrapid vehicles are flexibly configured to correspond with the requirements of the most diverse applications. The vehicle sections are built using lightweight, modular structures and can be combined into trains with two to ten sections depending on the application and traffic volume. Together, the vehicle body and the maglev undercarriage form a vehicle section. Each vehicle section has four levitation chassis which serve to transmit the forces for propulsion, support, guidance and braking. To ensure optimum travelling comfort, the levitation chassis are connected to the vehicle body via a self-leveling air spring and pendulum suspension.



The Transrapid is not only fast, but it can also accelerate quickly to high speeds. 300 km/h (185 mph) can be reached after a distance of only 5 km (3 miles). Modern high-speed trains require more than 28 km (18 miles) and at least four times as long to reach the same speed! The favorable aerodynamic properties and the non-contact technology make the Transrapid extraordinarily economical. At the same output the superspeed maglev system consumes 20 to 30 percent less energy than the already very “modest“ railroad.

For the same transportation performance, the specific primary energy consumption of automobile traffic is 3 times and air traffic 5 times higher than the Transrapid. Compared with other transport systems, the Transrapid is extremely quiet. There is no rolling or propulsion noise. At speeds up to 250 km/h (155 mph), the Transrapid hovers almost soundlessly through cities and metropolitan areas, at speeds above the noise emission of the superspeed maglev system mainly characterized by aerodynamic noise. At higher speeds like 300 km/h the noise level is 10 dB (A) lower then the ICE or the TGV (An increase of 10 dB(A) is perceived as a doubling of the volume of noise).

For high energy efficiency reasons, the magnetic field used for the levitation, guidance, and propulsion of Transrapid is concentrated within the gap between the vehicle and the guideway components of the linear motor. Outside this gap, the intensity of magnetic stray fields strongly declines. In the passenger cabin the level is within the range of the earth´s natural magnetic field. And mobile phones work without any problems in the vehicle.

Due the non-contact and non-wearing technology, maintenance of the vehicles, the guideway and the guideway equipment is primarily restricted to the conventional structures, unless damage occurs through external influences which cannot be foreseen.

In a comparison of the maintenances cost of the Transrapid system with conventional high speed rail, the Transrapid costs are one third less. In comparison with other transportation systems, the Transrapid maglev system requires the lowest amount of space and land for guideway infrastructure and related facilities.

Length end section: 27 m
Length middle section: 24.8 m
Width: 3.7 m
Heigth: 4.2 m
Maximum operational speed: 500 km/h (310 mph)
Empty weight passenger vehicle per section: approx. 53 t
Empty weight cargo vehicle per section: approx. 48 t
Useful payload, cargo vehicle per section: approx. 15 t
Seats, passenger vehicle end section: max. 92
Seats, passenger vehicle middle section: max 126

Some figures of the maglev – vehicles

Industrial minerals are used for the production of the statorpacks:

One statorpack is about 1 meter long, 300 mm wide and weights 112 kg and is made of electrical-steel with a resin coating. This serves as a protective coating against corrosion.

These statorpacks are mounted on both sides of the guideway, which means that for 1 kilometer of track one needs 2000 statorpacks. In the process is the so called „automatic pressure gelation process“. Several components are mixed together and then filled under vacuum into the mold.

One the most important components is the Silbond Quarz from Quarzwerke Frechen, which is used as a filler to give the epoxy resin coating its stability and durability. Besides the co-efficient of expansion under heat is very small, which is a very important factor considering the small tolerances of the guideway and vehicle.

Industrial Minerals in Paper

By Mr Jouni Malmivaara

Vice-President Material Management, UPM-Kymmene Corp., Finland

Summary

This paper focuses on the role of minerals in papermaking and especially in the overall performance aspects, competitiveness, key supplier criteria for serving a global customer in pigments and how a global paper company manages its procurement. As a Sourcing professional I would like to concentrate in the commercial elements of minerals in today's Paper industry.

Paper and board production has been growing rather steadily 2-3 % annually reaching now ca. 330 million tonnes globally. Pigment usage in paper instead has grown even faster – from 10,4 m tonnes (1980) to 27,0 m tonnes (in 2000). This growth trend depends now highly on the end user needs and paper property development, but can also be reinforced by mineral producers own development processes/decisions. If and when the paper prices will continue to decline over the coming years, it is probable that with right performance results and efficiency improvements pigments could increase still there share in paper. This also means emphasis on R&D work, improved cost performance and price competitiveness against other paper components.

Competition between different pigments and pigment solutions is increasing and more combinations are emerging the market. Although main business is still done in bulk minerals, increasing number of special solutions are developed together with Paper industry. Listening to paper producer is very important in order to keep the right price – performance ratio. Brightness of paper has been growing steadily, but we should any way keep up the differentiation of paper grades – because paper prices cannot be raised by higher cost pigments. Paper industry fights against other media and we must keep our competitiveness very good – so cost minimization is the driving force in all production.
This puts pressure also to Pigment producers to continuously rationalize, search for better, more efficient processes and combinations. Balancing with special performance, excellent service and value-add offerings minerals producers must always look at total costs, right input in R & D and competent staffing.

UPM-Kymmene's Materials Management is responsible for the worldwide provision of materials and services to 22 paper mills and several other business entities. We manage our procurement through a network of Global Sourcing Teams. These teams consist of Materials professionals from production sites around the world together with operational and technical staff where appropriate. The teams are responsible for the creation and implementation of sourcing strategies for e.g minerals. Main elements in these strategies are e.g. Key Supplier selection and development processes. All suppliers go through a process of Supplier relation management with 6 stages:
basic survey, acceptance, positioning, guidelines, evaluation and development. We want to operate with so-called future winners – in other words those who can meet the competition, serve us longterm and fullfil our needs regularly worldwide.

Pigment sourcing is as well very global and also very local, but for UPM-Kymmene with a need of total 2,2 million tonnes, it is also capacity management, creation of righ product-mix and optimization of logistics. All these issues must be developed together with Key Suppliers and therefore longterm relations, harmonized terms and practices are a key to success.
We want our Key Suppliers to:

Avoid: Arrogance – Average – Greed
Increase: Drive – Openness – Global way of doing business

High-Tech Ceramics in Ballistic Protection

By Mr Ekkehard H. Lutz
and Mr H. Hoppert

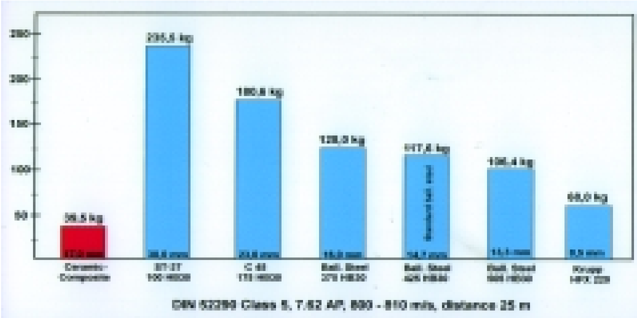
Summary

High-Tech Ceramics are used in a wide range of different applications due to their characteristic properties. On the one side their special active electric and magnetic behaviour allows them to be used as semi- and superconductors as well as thermo- and ferroelectric devices in sensoric, adaptronic and actuatoric applications.
On the other side most ceramics are of low density, but high Young`s modulus, strength and hardness. These properties make some of them, like alumina, silicon carbide and boron carbide superior even to special steel grades when it comes to the protection of human life against gun and rifle ammunition, exploding mines and mortar fragments.
Within this presentation the mechanisms and background of the ballistic efficiency of such materials are explained. In addition, it is demonstrated how and where high-tech ceramics are successfully used for personal and vehicle protection.

Introduction

Ceramic materials are brittle and therefore susceptible to impact. In spite of this, they provide an enormous ballistic potential of protection. In comparison to ceramics, armor steel is ductile and shock-resistant, and has proven its efficiency in many different applications. Despite this fact, during the military operation "Desert Storm" Americans have used add-on ceramic plates for the armoring of tanks and transport vehicles, which obviously has helped this material to get accepted worldwide.

Initial successful tests on the application of ceramic materials and their protective effects for armor protection have already been reported in the early sixties. Today, composite materials consisting of ceramic and metal or ceramic and polymers are state of the art since long, and they have proven their efficiency during numerous applications. This is to be attributed to their high ballistic performance and their notably reduced weight per area.



As it can be seen in Fig. 1, the weight per area of ceramic composite armor is up to 60% lower than armor steel at the same performance level. Nowadays, the ceramic materials most frequently used are mainly alumina, silicon carbide and boron carbide.
Among these, alumina materials with density values of 3,8-3,9 g/cm³ are still the most important ones, a fact which can be attributed to the relatively low raw material prices and low production cost. In comparison, the raw material prices and production cost of silicon carbide (density approx. 3,2 g/cm³) and boron carbide (density approx. 2,5 g/cm³) are considerably higher. A low weight per area can only be obtained by using expensive ceramic materials.

Construction of ceramic composite armor systems

The basic principle of these light weight armor systems is based on a composite construction of ceramics and polymers. Within these systems the four components perform different functions: the front side of the composite armor consists of ceramic plates (generally alumina is used because of its relatively low cost). For the backing are used **highly resistant** and highly elastic polyaramide tissues (Twaron, Kevlar) or polyethylene. An impregnation with rubber or hardening polymers with defined adjusted shore hardness values provides the necessary rigidity and ductility.
An alternative material to polyaramides as backing material are glass fibre composite materials. In addition, a spall liner is fixed on the front side of the ceramic. A great strain is put on the ceramic/backing composite, and for gluing are used exclusively high-performance adhesives.

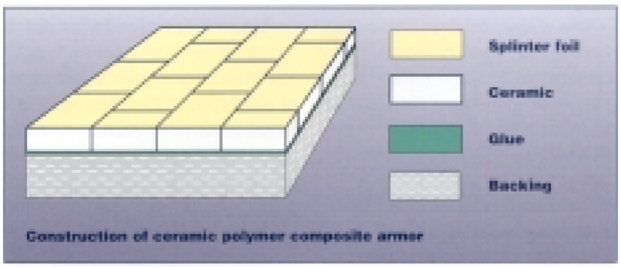


Fig. 2: Structure of a ceramic/polymer composite armoring

Protective Mechanisms

The protective action of metals (steel, titanium, aluminium alloys) is based on the high plastic ductility of materials. The kinetic energy of a bullet is completely transformed into deformation and heat. The high bouncing of the bullet causes high frictional forces, leading to abrasion and finally breaking of the **penetrator**. Problems may arise when hardcore ammunition is used (e.g. with tungsten carbide core). Due to its high hardness, the abrasion resistance of the bullet core reduces notably the destruction (micronization) of the penetrator.

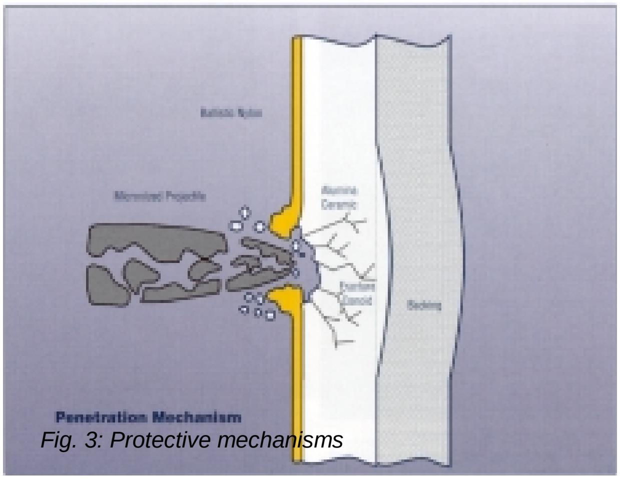


Fig. 3: Protective mechanisms

Contrary to this, the protective effect of ceramic materials is based on a totally different mechanism of reaction. Not too long ago it was supposed that kinetic energy is completely transformed into fracture energy. Today it is known that the fracture energy makes up less than 20% of the total energy. Based on these findings, it can be assumed that the following mechanisms of reaction take place during such a process:

When hitting the ceramic surface, at first the bullet tip is deformed, meaning that the cross-sectional area is enhanced, and consequently, the pressure load is reduced. This is due to the high hardness, the high elasticity modulus and the high resistance to pressure of the ceramics. Now it is important that the pressure wave originating from the impact passes through the ceramic with a velocity of more than 10.000 m/s. At the backside of the ceramic the pressure wave is reflected and returns as a tractional wave. Impact and frictional processes, but above all the interaction and superposition between the pressure wave and the tractional wave cause a micronization of the penetrator. Owing to this, after penetrating the ceramics there only remain fragments of the bullet. Because of their low mass, the kinetic energy of the fragments is considerably lower, and is completely absorbed by elastic/plastic deformation within the backing. *(see Fig. 3)*

More detailed knowledge about the occurring mechanisms within the ceramic and the bullet can be obtained by means of X-ray examinations and analysis of the penetration process. Six different partial processes can be recognized. The total process for stopping the bullet is finished as early as after 60 microseconds. The bullet moves towards the target with a speed of approx. 850 m/s (calibre 7,62 mm, length 27,9 mm, total weight 10,6 g)

0 µs. The bullet is just going to hit the ceramic surface

7 µs. The lead tip and the steel jacket have already penetrated the ceramics and is notably deformed.
The hard core, on the other hand, has just reached the ceramics. In front of the penetrating object a cylindrical, rigid and viscoplastic area is formed. This is indicated by the concavities formed in the ceramics at the edge of the penetration cone, which can only be explained by the fact that plastic flowing is taking place. In comparison to this, no defect due to crack formation at all can be recognized at the ceramic.

17 µs. The hard core has also penetrated the ceramic. Within the ceramic material, a fracture cone is formed the diameter of which is about four times the size of the bullet diameter. At the same time, a dust cloud of erosion particles from the ceramics and the penetrator is laterally shaken out. It can easily be recognized that a buckling was formed at the penetrator and thus, a broadening of the effective cross-sectional area.
In front of the penetrator the ceramic is considerably affected by longitudinal and radial cracks. Furthermore, it is important to note that the speed of the penetrator was reduced from 850 m/s to 230 m/s.

25 µs. The process of penetration is continued while strong deformation is taking place. At the same time, the ceramic is further destroyed. The intense bulging of the ceramic materials towards the backing indicates that within the ceramic material viscoplastic flowing continues to take place.

35 µs. The speed of the penetrator is further reduced to now 170 m/s. It is interesting to observe that the hard core stays notably behind in comparison to the steel jacket.

45 µs. Between 35 and 45 microseconds the penetrating object continues loosing kinetic energy. The penetration speed of the hard core in the final phase is without any significance. Its fragments are deviated by the ceramic fragments, and its residual speed is retarded by the backing. The complete penetration process is finished after 55 microseconds. As far as the bullet is concerned, the figure only shows a part of the bullet amplified to the double of its original size.

By means of this model, the reaction mechanisms during the penetration process can be clearly described. However, the effect caused by the shock waves resulting from the bullet striking the ceramic is not considered.

A shock wave emanates from the point of impact which, after having crossed the ceramics, is reflected with a speed of more than 10.000 m/s as a tractional wave at the intermediate layer ceramic / backing. The same applies also for the bullet. Particularly in the crossover area of shock and tractional waves this may cause splintering or micronization both within the ceramic and within the bullet. These effects which owing to their complexity cannot currently be controlled yet, take place within very few microseconds. The shock wave needs about 1 microsecond to cross the ceramic with a thickness of 10 mm. In case of repeated reflection of the waves, the process of destruction of the ceramic and of the bullet should have been widely finished after 6 microseconds. This statement, however, is contradictory to the X-ray illustrations shown here, where we can see that both the ceramic and the bullet are still in relatively good conditions. Except for a notable plastic deformation of the penetrating object, no further damages can be recognized.

Ceramic materials – State of the Art

Based on the state of the art of today, the following ceramic materials are currently used:

Alumina materials:
Al_2O_3 contents 92 - 99,5%
Density ρ = 3,7 bis 3,9 g/cm^3

Silicon carbide:
Density ρ = 3,0 - 3,2 g/cm^3

Boron carbide:
Density ρ = 2,5 g/cm^3

Alumina continues to be the most important ceramic material, which is due to the fact that its raw material cost is relatively low, that the production technique is well mastered, and that the required sinter processes can be carried out in air atmosphere. It is not just the price which is the decisive factor to use alumina, but the ballistic performance of this material is equally important. In comparison to silicon carbide and boron carbide, the only disadvantage of alumina is its relatively high density.

There are two kinds of silicon carbides available in the market today: S SiC (**s**intered **s**ilicon **c**arbide) and LPS SiC (**l**iquid **p**hase **s**intered **s**ilicon **c**arbide).

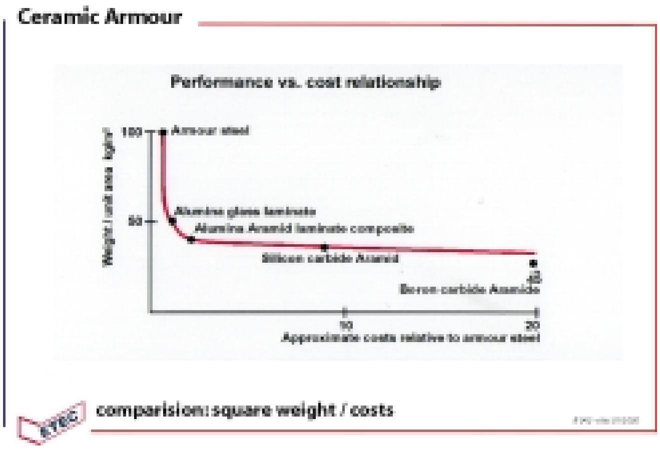
Whereas S SiC consists virtually of 100% silicon carbide, the LPS SiC contains furthermore sinter additives (approx. 10%) in the mixing. Aspects regarding functional efficiency argue for the use of LPS SiC – but above all, a decisive issue is the far lower production cost in comparison to S SiC. Hot pressed silicon carbide materials (HP SiC = **h**ot **p**ressed **SiC**) require a more expensive production technology, and silicon infiltrated (or reaction bonded) silicon carbide (SiSiC) though cheaper do not provide the same ballistic performance to our knowledge.
An interesting alternative not discussed here is the group of silicon nitrides that are tougher, but still very similar in properties to the silicon carbides. Also for boron carbide (BC) the technology of liquid phase sintering is preferably used, but there are also hot pressed qualities available in the market.

Fig. 5 shows the density and weight per area of the ceramic per square meter, and the weight per area of the system. Δm is the weight gain compared to Al_2O_3.

△	Density g/cm3	Weight of ceramics kg/m2	Weight of the system kg/m2	m in kg	m in %
Al_2O_3 (96%)	3,80	30,4	40,9	-	-
SiC	3,21	25,7	36,3	-4,6	11,2
BC	2,50	20,0	31,6	-9,3	27,7

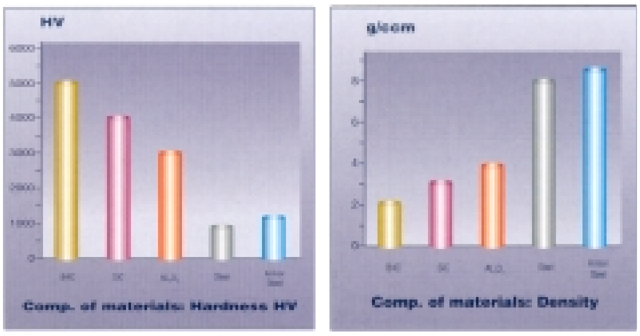
Fig. 5: Density and weight per area of different materials

With the materials available today, it is possible to comply with the requirements of the highest European protection category B 7 by means of using alumina (96% Al_2O_3), silicon carbide and boron carbide. The backing used was an aramide laminate with 18 layers of rubberized Twaron.



From this circumstance is derived the major market requirement of reducing the weight per area for protection systems. The following graph compares the price/efficiency ratio of different protection systems. In accordance with the state of the art, it will only be possible to reduce weight by means of using ceramic materials with a reduced weight. This, however, implies a price increase for the system.

When reflecting about how to improve ballistic protection, it has to be taken into account that ceramic composite armoring has to be considered as a system. The individual components of this system have to fulfil different functions. It is the task of the ceramic to micronize the bullet, and the function of the backing is to absorb the residual energy. This is why there are different requirements made to the individual system components. The ceramic material has to comply with the following functions: High hardness, High elasticity modulus, High sonic velocity and Low weight per area.



The graphs above show, for example, the hardness and density values of different ceramic materials in comparison to steel.

The requirements made to the backing can be characterized as specified below:

- High tensile strength
- High elasticity
- Low density
- High energy absorption capacity
- High vibration resistance
- Low aging

For all kinds of ceramic composite armor systems it must be taken into consideration that the backing has to be adapted to the properties of the ceramic. In many cases it will become necessary to provide a support for the ceramic in order to avoid that its brittle behaviour will cause damages to the system.

As described above, today there is a relatively broad knowledge of the protective effects of ceramic/polymer composite systems. In order to confirm whether a particular system is suitable for a certain threat level, ballistic tests are indispensable in order to make sure whether the systems perform sufficiently in practise. Current ballistic tests are the V_{50} – test (determination of the average speed for 50% bullet penetration) and the Vo-test (determination of maximum critical velocity without bullet penetration).

Whereas the determination of maximum critical velocity is of basic importance for the layout of the system, the V_{50} – shooting is used, among others, to obtain the authorization for productions of the proposed system solution.

Ballistic requirements are codified by technical standards, e.g. the German Police Standard DIN 52290 or NIJ – Standard (National Institute of Justice USA). In Europe, the European Standard (CEN European Standard) is more and more applied. According to the threat levels, the protection levels are divided into seven different sections on the basis of calibre, bullet type, bullet weight and velocity).

Applications for Body Protection

Composite systems consisting of ceramic and polyaramide or polyethylene backings provide maximum protection against direct firing with hand firearms (B5 to B7), and against explosive and splinter action. In case of danger commercial bullet-proof vests can be easily reinforced by matching ceramic/polymer inserts.

Inserts based on curved 50 x 50 mm tiles with curvature radii of 200 mm to 400 mm. These inserts provide maximum protection even in case of multi-hit firing. The advantage is that only single tiles fracture upon impact whereas monolithic inserts can develop a major crack which reduces the impact resistance considerably for subsequent shots.

Because of the increased wearing comfort they provide, ceramic monoliths have reached an important position in the market today. Generally, their dimensions are 300x250 mm. The wall thickness can be individually adapted according to the given threat level. Monoliths are available in different shapes (single curved, double curved up to multi curved).

Furthermore, protection shields made of ceramic and polyaramide are available for the protection of soldiers in areas of conflict.

Object Protection

In the field of object protection, generally plain rectangular tiles (dims. 100 x 100 mm and 50 x 50 mm) are used. The thickness to be chosen depends on the ballistic performance required, and is usually between 5 mm and 15 mm. Tiles specially cut to size, tiles with boreholes or chamfered edges are also available.
Ceramic composite armoring protects from direct gun fire, mortar and artillery fragments as well as from ground mines. The protection panels are assembled in a modular way. If the composite materials for the system are properly chosen, they will reliably comply with all requirements. The following important issues should be considered:

- Ceramic quality and dimensions of plates
- Type of backing and thickness
- Ensuring operating safety of the mounted panels, e.g. impact load, vibrations, temperature, climate

Ceramic composite armorings have proven to perform successfully in a big number of cases as light and medium level protection for vehicles as „add on armor“ or as integrated interior protection. Not without good reason, the vehicles of the German Army for their mission in areas of conflict, for example, in Bosnia, in Kosovo or now in Macedonia are being equipped with add-on ceramic armor in order to ensure maximum protection. Typical examples are shown in the following photos:

Further examples: MB 2638 by Daimler and KAT 1 by MAN (only to mention the most important ones)

Development

According to the current state of the art, the objective of development can be characterized as below:

- Improvement of existing materials, aiming at increasing the ballistic performance by means of an improved production technology
- Development of new materials with low density values and a high ballistic performance
- System development aiming at designing composite solutions with increased efficiency

Improvement of production technology

Highest requirements are made yet today to ceramic production technologies when ballistic applications are concerned. The absence of cracks and pores for all components is a matter of course. The finished tiles are only allowed to show very slight damages at the edges and angles. A bulk density value of at least 97% of the theoretical density must be achieved. The same importance as a reproducible and error-free production for each individual ceramic plate is the fact to ensure that extremely tight tolerances regarding dimensions, plane parallelism and evenness are observed. Only if all these requirements are met, close-jointed laying can be guaranteed. This is extremely important because each joint broader than 0,3 mm will be a weak point which may have negative influences on the ballistic strength. Furthermore, it is a matter of course that all relevant physical properties are observed.
Indispensable prerequisites to meet these requirements are the following ones:

- Careful selection of raw materials and additives
- Controlled and reproducible preparation of raw materials
- Absolute expertness concerning the forming and sintering technology
- Overall Quality Management during all production stages – from the powder stage until the finished product

It is a continuous challenge to the ceramic manufacturer to improve the production technology. Whereas no substantial improvements regarding the performance and weight saving can be expected, by means of an increase in the theoretical density of, for example, from 97% to 98% a weight reduction of about 5% by increasing the ballistic strength can be obtained.

Development of new materials

Today, the following materials are applied, or their possibilities of application are currently discussed:

- Various alumina materials
- Boron carbide, cubic boron nitride
- Silicon carbide
- Titanium carbide
- Silicon nitride, aluminium nitride
- Ceramic composite materials
- Metal / ceramic composites
- Fibre or whisker-reinforced ceramic materials

For **alumina materials** there still exists a certain potential of development which however is limited by the relatively high density of corundum (3,99 g/cm^3). Progress can be achieved by means of materials with a contents of more than 99% Al_2O_3.

As to **boron carbide,** this material is nowadays nearly exclusively used for helicopter and plane armoring. Possibilities of application are limited by the elevated cost of boron carbide.

Due to its physical properties, **cubic boron nitride** is a very interesting material, but unfortunately the cost of this material is still higher than the cost of boron carbide.

From our point of view, the most important potential of development is to be found in the range of **silicon carbide** materials, but also for these materials the main problem is the relatively high raw material cost and the expensive production technology.

Because of its relatively high density of approx. 4 g/cm^3 **, Titanium carbide** as a pure ceramic material has only few prospects of success. Titanium carbide, however, is interesting as an additive for alumina and possibly for silicon carbide.

Because of its higher fracture toughness in comparison to SiC and Al_2O_3, silicon nitride could possibly be an alternative for the future. From its physical properties an improved multi-hit resistance can be derived. Higher raw material prices and a lower hardness of this material, however, argue against an application on a broader basis. Due to its low hardness, however, we don't believe that there will be a substantial potential of application for **aluminium nitride**.

For carbides and nitrides hot pressing is an alternative to increase their performance in comparison to sintered products. However, due to its higher this technology is not so widespread.

Research for development of **ceramic composite materials** is done world-wide. Nevertheless, from today's point of view no substantial progress can be recognized yet. Zirconium-reinforced alumina didn't show any significant improvement of performance during ballistic testing. Al_2O_3 / SiC – composites have not yet been well engineered, whereas Al_2O_3 / TiC – composites have been showing good results in the field of wear protection. However, owing to its high cost these materials cannot be considered for series application for ballistic purposes.

It is known that **metal / ceramic composites** are appropriate materials for ballistic applications. For example, "Lanxide" material was employed by the U.S. Army as a protection material during "Desert Storm" (Gulf War) as „add on armor" for battle tanks and military vehicles. The material in question is a Al_2O_3 / Al or SiC / Al – composite.
Lanxide shows a good multi–hit resistance, however, the ballistic performance of Lanxide is notably lower compared to alumina. Recent studies and testing in Switzerland didn't have any satisfactory results – above all, the density values and thus, the weight per area was notably above the values obtained with alumina.

Whisker-reinforced materials can virtually be excluded from any consideration because of their high cost and due to product engineering reasons. In addition, whiskers are extremely toxic which is a further argument against their use.

Basically, long-fibre reinforced materials are highly promising regarding their ballistic potential. Among these, C-SiC, a carbon-fibre reinforced silicon carbide material, is the most outstanding material. Its extremely low density of approx. 2,7 g/cm^3, in addition to a high rigidity, are interesting properties of this material. However, its ballistic performance is not yet sufficiently high in order to be compatible particularly with known SiC concepts. Today, an argument against C-SiC is still the high cost of carbon fibres and the fact that the production technology is not yet sufficiently mastered. Once these problems are solved, C-SiC could also be an interesting material for ballistic applications, because except for SiSiC it is the only ceramic material suitable for manufacture of components with complex and large shapes.

Borates and the Hydrogen Economy: Driven by Customer Demand

by Stephen S. Tang Ph.D.

President and CEO
Millennium Cell, Inc.

Summary

Some say the hydrogen economy is right around the corner, others that it's a pipe dream tied to speculative technologies too remote to matter. In the discussion, not enough attention has been paid to what we believe will be the major impetus behind the migration to a hydrogen economy – market pressure from consumers.

Energy supply uncertainty coupled with rising prices is eroding customer confidence in current energy systems. Demand for energy has never been higher, as new technology creates an ever-growing need for high quality power. On a policy level, nations are realizing the increasing imperative of energy independence. Consumers are looking for alternatives – and they want those alternatives to be clean, quiet, dependable and portable.

Hydrogen is the answer – if we can solve both the hydrogen generation and storage challenges. Safety and consumer acceptance of the technology are paramount. The use of a chemical hydride system to safety store the energy contained in hydrogen, releasing it only in the presence of a catalyst under controlled conditions for immediate use will, we believe, play a major role in enabling the reality of a full hydrogen economy.

The presentation will discuss the market drivers that will create the hydrogen economy, present a summary of the challenges inherent in its implementation, and the role of Millennium Cell's Hydrogen on Demand™ system in meeting those challenges.

Introduction

The presentation will address the unique role that borates play in the emerging hydrogen economy and Millennium Cell's role in advancing it. As you can surmise from its title—"Driven By Customer Demand"—it will focus on the needs of the most important stakeholder in the emerging hydrogen economy—the customer. In the past year, Millennium Cell has begun to take a leadership role in identifying and addressing customer needs. What we have to share with you today is a message that we have shared with our customers and prospective customers, investors, public policy makers—including colleagues on the U.S. Department of Energy's Hydrogen Vision Team, and thought leaders in the Americas, Europe, and Asia. We are pleased to report to you that—so far—it has been very well received because of its simplicity and matter-of-fact approach. Yet, as you will see and hear in the remarks, "clarity of purpose" does not mean "ease of execution. In fact, our work in that regard has only just begun.

Let us gaze into the future of a world replete with clean energy and offer forward-looking statements of our company's role and intentions.

The presentation consists of three main parts:

•"Market Drivers And Challenges" for the emerging hydrogen-fuel infrastructure

•"Three Myths" that have clouded our vision of hydrogen and "Three Realities" which will help us create better roadmaps for the future;

•Millennium Cell's progress on bridging the gap from vision to reality

Market Drivers And Challenges

Everyone is aware that fuel prices are volatile – many have more than doubled in the past few years. Since September 11th, whatever patience the world's industrial economies have had with that volatility has given way to broader concerns about geo-political stability during our war on terrorism.
Last year, Americans were subjected to gross exaggerations about California's energy crisis, creating cynicism about many energy issues from deregulation to reliability and power quality for the digital age. The coupling effect of ever more stringent clean air requirements, including carbon dioxide emissions, means that we will apparently need to use less, not more, fossil fuels.

As the American environmentalist John Holdren recently observed: "The most serious problem that we confront is not that we are running out of energy, but that we are running out of environment…of the capacity of air, water, soil, and biota to absorb…the effects of energy extraction, transport, transformation, and use."

The interplay of these factors creates both challenges and opportunities for purveyors, like Millennium Cell, of alternative fuel technology and sustainable development. We urgently need innovation, investment, and results to solve the world's energy conundrum.

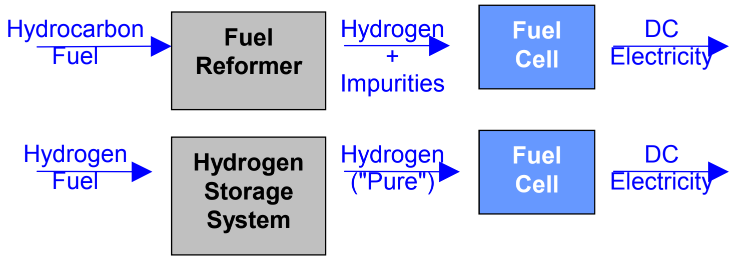
Hydrogen is clearly a better natural choice for high energy content and for a cleaner environment. The comparisons to coal, oil, and natural gas, by now, are familiar and misleading. Most people cannot intuitively or literally grasp what a pound of hydrogen is or could be in everyday human experience. Smart people compound the issue by reminding their fellow earthlings that 98% of the universe is composed of hydrogen. The response: So what? It's as if some people assume that the hydrogen-fuel economy is inevitable. In intergalactic terms, it may be…if we are prepared to wait the necessary light-years at warp speed. But for us mere humans trying to make clean energy a reality today, there must be ways that we can make hydrogen more approachable and in demand by other humans who are willing to pay real money to buy it—namely customers.

On the playing field of alternatives, today, there are two types of hydrogen-fuel systems. Both types are far from technological maturity.

Fuel Reformers are complex multi-step chemical refineries that create hydrogen gas from hydrocarbons like gasoline and methanol. Advantages include the wide availability of hydrocarbon fuels in cost efficient quantity. Disadvantages, as reported by many experts include:

- Gaseous impurities that harm the fuel cells
- High equipment cost
- Large space and heavy weight requirements for the fuel and equipment
- High operating temperatures
- Poor load-following characteristics that sub-optimize fuel cell performance, and
- Carbon sequestration and noxious emissions problems

Hydrogen Storage Systems are mechanical or chemical means of holding hydrogen as a gas, liquid, or solid.



Advantages include the provision of pure hydrogen to the fuel cell with well-matched with the variable needs of power equipment.

The main disadvantage of these systems are—

- The total cost of creating and storing the hydrogen in the system is higher than hydrocarbons today
- Lack of infrastructure for gaseous hydrogen today
- Large space and heavy weight requirements for the fuel and equipment for all systems except Millennium Cell's *Hydrogen On Demand* technology.

So within this hydrogen playing field, it is clearly a foot race to solve the technological and cost-reduction challenges.
This race to create the ascendant technology for hydrogen-fuel is difficult to handicap. If you take out the bias created by those who have a vested interest in one technology or another, you are left searching for intellectually honest questions to help you locate the pathway beyond technological success to commercial success.
To do so, we need to distinguish myth from reality…

Three Myths and Three Realities

Here are "Three Myths" that we must overcome to clearly see the future from the eyes of the customer:

1. The future hydrogen-fuel infrastructure will ultimately have a universal supply chain—primarily linked to transportation (hydrogen gas stations, for example)
2. Hydrogen-fuel infrastructure is about creating supply chains to move and store gaseous hydrogen, with steam methane reformers on every street corner, if you believe some predictions.
3. Consumers will accept higher costs, compromises, and inconveniences because hydrogen-fuel it is good for the world and/or its mandated by governments. That myth, by the way, should have been dispelled by

the commercial failure of battery electric vehicles. But, we seem to have short memories.

In contrast, here are the "Three Realities" that I hope we will consider in making choices for hydrogen-fuel supply chains and infrastructure:

1. Fuelling experiences today vary by power application and need and are supported by many supply chains
2. Supply chains for stable liquids and solids are more appealing and feasible than those for gases
3. Consumers are likely to switch to hydrogen only when the benefits to the end-user outweigh the cost

Let us now contrast each myth and reality by framing each issue as a succinct question.

Issue 1: One or many supply chains?

Fuel cells are evolving to serve a variety of power needs. Driven largely by cost reduction of PEM fuel cells, we expect products to debut over time in—

•Portable and Specialty Power
•Commercial Power
•Residential Power, and finally in
•Transportation

If the customer's fuelling experience for each of these power applications is <u>different</u> today, why <u>should</u> we expect that diversity of experience will end with hydrogen as a fuel? The contrasts may be pinpointed as follows:—

- Portable And Specialty Power requirements are today satisfied with consumer purchases of self-contained solid-state disposable batteries and liquid fuels like butane lighters;
- Residential And Commercial Power needs are met with propane tank exchange businesses and delivery of home heating oil or gases
- Transportation Power is obtained by those favorite petrol or gasoline stations that we patronize based on convenience and competitive pricing

Now here's a "not-so-bold" prediction: "the equipment and devices that include fuel cell technology will be marketed and distributed through many of the <u>current</u> channels." That might seem blindingly obvious to all of us. But the implication of that prediction is that we will have to find a way to have the hydrogen-fuelling experience marketed and distributed through these same channels.

As you read through this incomplete list of possibilities, think of your favorite home appliance, consumer electronics, pharmacy, and grocery stores. Each of these stores represents a customer-facing stakeholder in the emergence of a diverse hydrogen-fuel supply chain and infrastructure to service a wide-range of customer fuelling experiences.

Issue 2: Solid, Liquid, or Gas?

Our collective experiences in the chemical, energy, or minerals industries have <u>not</u> demonstrated many of the core capabilities that we will need to create and manage global supply chains for explosive gases like hydrogen.

In spite of great strides in remaking hydrogen's image years after the Hindenburg and Challenger space shuttle disaster, one simple fact remains: Consumer acceptance, familiarity, and convenience overwhelmingly favor stable solid fuels or stable liquid fuels over gases of any kind. There are surely many examples in the industrial minerals experiences that would validate that observation.
Therefore, shouldn't we engineer that basic preference into the <u>design</u> of our hydrogen-fuel before we begin designing its supply chains and infrastructure?
The answer to that question is obviously "yes!"
It is the essence of Millennium Cell's vision and mission for the hydrogen economy.

Issue 3: What do consumers want?

Simply put: consumers want it all. Consumers do have a well-understood baseline of experiences to compare the benefits of today's fuels and fuelling experience for, say, petrol or gasoline, to any fuel that they might consider buying and perhaps paying more for in the future.

All things being equal, if someone could develop the technology for cars to run on a hydrogen-fuel as robust as gasoline, yet closer to safety and handling features of mineral water, consumers would switch to that hydrogen-fuel because they and their automobiles would enjoy the benefits of the technology because they "get more" benefit and don't have to "give up" much in return.

According to Millennium Cell's business partners in the automotive industry, that's called an "attractive value proposition." And value propositions will probably define success or failure in hydrogen-fuels, since they will likely be more expensive that today's fossil fuels as they debut.

So, against the headwind of these issues, **how can the hydrogen economy move forward to reality?**

Hydrogen-fuel will be successful when it “wins” in four ways:

1. Hydrogen-fuel offers performance and benefits equal to or better than gasoline
2. It has lower “wells-to-wheels” emissions and better CO2 containment than fossil fuels
3. Its resulting supply chain and infrastructure offers profits for power technology companies who make the fuel cells or end-use equipment, and
4. The supply chains and infrastructure offer profits for hydrogen manufacturers and distributors and incentives to reinvest in assets that produce hydrogen from a variety of feedstock.

These four criteria point the way towards market-based success for hydrogen-fuel.

It is not a coincidence that they form the basis for Millennium Cell’s business strategy of partnerships throughout the energy technology industry.

Millennium Cell's Hydrogen on Demand™ System

$$NaBH_4 + 2H_2O \Rightarrow NaBO_2 + 4H_2 + \text{Heat}$$

- $NaBH_4 + 2H_2O$: 20-35% $NaBH_4$ solution, stabilized with ~1-3% NaOH
- ⇒: Proprietary catalyst induces instantaneous hydrogen production
- $NaBO_2$: Metaborate ("Borax") in aqueous solution with NaOH
- $4H_2$ + Heat: Pure humidified H_2 delivered to a fuel cell

Millennium Cell’s **Hydrogen On Demand System** stores hydrogen in the chemical bonds of sodium borohydride.

When sodium borohydride, NaBH4, is dissolved and stabilized in water, and used with fuel cells, the fuel system has an energy density closer to gasoline than any known commercially-viable hydrogen-fuel system. It is a non-flammable liquid fuel that can be transported easily.

If and <u>only</u> if the fuel is induced by a proprietary catalyst does it release hydrogen at the rate that it is consumed by the fuel cell. Our trademarked name “Hydrogen On Demand” appropriately describes this technology that produces gaseous hydrogen only when needed. So does our moniker “Freedom Fuel” for our water-based sodium borohydride fuel. Customers using Freedom Fuel <u>are</u> free from the inconveniences, uncertainties, and safety concerns inherent to handling, storing, and using explosive gases.

Note that the sole, unconsumed by-product of the Hydrogen On Demand™ system is metaborate. For large-use applications like transportation, we envision the borate to be completely recyclable through an off-board process to regenerate sodium borohydride.

Millennium Cell has adapted Hydrogen On Demand technology to various applications in Distributed Generation and Transportation. We have also recently completed a study that <u>favorably</u> compares the benefits and costs of sodium borohydride-based technology to other hydrogen generation and storage technologies.

For Distributed Generation, we design and sell a series of Millennium Cell NX-1 Development Systems to enable power generation product design engineers and fuel cell manufacturers to experience the benefits of our water-based sodium borohydride fuel in a convenient tank-swapping configuration. The tanks are modified liquid propane cylinders that could be handled through existing fuel suppliers in the LPG business.

Based on the product and customer knowledge of our business partners, we anticipate high demand for Millennium Cell’s *Hydrogen On Demand* systems as economic replacements <u>today</u> for lead acid batteries and other inferior standby power value propositions. For example, we are now working to meet the needs of the 25,000 internet data centers worldwide, the 20,000 or more new cellular phone towers built every year, and over 800,000 pieces of residential standby power equipment sold every year.

In transportation, DaimlerChrysler and Millennium Cell were pleased to deliver our concept car—The Natrium™--to the California Fuel Cell Partnership, in April, for the start of it's global "ride and drive" demonstrations. Next week, the Natrium will begin its European tour beginning with a visit to Stuttgart, Germany for the DaimlerChrysler Innovation Symposium.

The Natrium is the world's first fuel cell prototype vehicle designed and built on a production-ready chassis and body that will travel 300 miles on a single tank of fuel. Because sodium borohydride-based fuel is near the energy density of gasoline, Millennium Cell's hydrogen fuel system is easily designed into the lower perimeter of the car.
What's more, because our fuel is non-flammable and non-explosive, it is designed to fit between the rear axle and rear bumper of the vehicle.

Those of us old enough to remember the tragic explosion hazards in the Ford Pinto know that no gasoline fuelled vehicle could be designed with the same positioning of Millennium Cell's fuel tank on the Natrium.

The Natrium is also the only fuel cell car designed to preserve <u>all</u> the passenger and cargo space that families are accustomed to today in their minivans. As you can see in this comparison, compressed gaseous hydrogen tanks would turn one of the world's best-selling 6-8 passenger minivan into a 4-5 passenger sedan with less cargo space than the infamous Yugo, with only two-thirds the distance range.

Now that The Natrium is in full view of the public and the auto industry, the stark contrast of Millennium Cell's hydrogen-fuel storage value proposition over high-pressure hydrogen gas storage has opened many eyes and ears.
In fact, that small piece of enlightenment has caused the energy technology industry to ask: "Will consumers ever willingly choose to compromise safety, familiarity, and convenience of a liquid fuel system for the privilege of carrying bulky gaseous hydrogen tanks with them to travel two-thirds or less the distance they are accustomed to between fueling?" The answer is probably "no".

One of the key commercialization challenges that we face as a company is providing cost-effective fuel for these transportation markets.

Millennium Cell has always acknowledged that today's market prices for sodium borohydride are too high for the needs of today's transportation market. In fact, <u>all</u> hydrogen-fuel systems have similar cost reduction challenges. Fortunately, we have leading business partners—such as Air Products & Chemicals and U.S. Borax to work with us to develop the new technology and manufacturing capability, based on many sources of energy, to produce sodium borohydride at prices that will compete with that of gasoline. In order to validate the trajectory of our cost reduction technology for sodium borohydride, we commissioned a technology-consulting firm to compare competing hydrogen-fuel alternatives in fuel cell vehicles.

The study revealed that:
Hydrogen On Demand™ will be <u>cost competitive</u> upon completion of current process development for SBH cost reduction;
Fuel cell vehicles equipped with *Hydrogen On Demand*™ will be <u>lower cost</u> than vehicles with fossil fuel reformers;
Hydrogen On Demand™ vehicles will have <u>key advantages</u> over all other hydrogen-fuel vehicles: Safety - Usable volumes in the vehicle - System integration

So in the race to optimize the cost of the fuel with the cost of the equipment to make and store hydrogen, Millennium Cell feels confident of our future with our fuel—Freedom Fuel™--designed for customer needs, acceptance, and energy independence.

In closing, we would like to say to our investors and business partners—including Rio Tinto's U.S Borax, who waited patiently and stalwartly with us through a stormy investing environment from 2000 to now, we say "thank you" and count on us to continue to earn your respect and trust each and every day.

People often ask how to define success today for an investor of Millennium Cell. That is a challenging question to answer for a CEO of any development-stage, intellectual property-based company selling emerging technology to an emerging marketplace. Millennium Cell's answer is this:

1. Continue to demonstrate that all of the major market segments of power technology are available to Millennium Cell's technology. These segments include portable and specialty power, stationary power for commercial, industrial, and residential settings, and transportation. Through the efforts of the entire Millennium Cell team, all of these markets are clearly accessible.

2. Show evidence through our partnerships that Millennium Cell's technology will earn significant shares of each of the major markets over time. Our success is in the names and prestige of our partners: Ballard Power Systems, DaimlerChrysler, PSA Peugeot Citroen, Air Products and Chemicals, U.S. Borax, and Rohm and Haas. And, finally

3. Set stretch goals focused on shortening the time-to-market of Millennium Cell's technology and meet or exceed them. In our annual report, you can read about our successes in 2001 and the goals which have established a rhythm for greater success in 2002. You should expect us to continue to be a leader in this practice. As long as we continue to have aggressive goals and the highest professional standards, our supporters should continue to believe that "the best is yet to come" from Millennium Cell.

Industrial Application of Nanocomposite Fillers Based on Organic Intercalated Bentonites

By Dr Thomas Engelhardt

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Nanotechnology appears to become a key technology of the 21st century. At present new products are intensively developed with the help of nanotechnology in various industrial and university research laboratories.

Whereas various fields of this technology are still in their infancy stage, a first commercial success could be achieved in the field of materials technology. Most progresses could be achieved in the development of new polymer material with nanometer architecture.

Nowadays, plastic material and rubber are applied in almost all areas of our life and still have a stimulating function for the development of future technologies.

In contrast to metallic resp. ceramic materials, plastic is relatively cheap, can easily be processed and has a variety of fields of application for textiles, packaging, automotive parts, furniture and household appliances. Plastic needs clearly less energy than ceramic or even metal for production and shaping. On the other hand, the isolation effect of plastics reduce the consumption of fuel oil resp. natural gas and – as a result – the emission of carbon dioxide.

In the automotive industry the - in comparison to metals - very light-weight plastics are saving weight and are very effectively contributing to a reduction in the need for fuel and in the emission of exhaust gases. About 100 kg of plastic substitutes about 350 kg of other materials. Per 100 kg reduction in weight half a litre of fuel is expected to be saved. If the project “3-litre-car” is to be realised, next to the car industry the plastic industry will be concerned with regard to the production of lightweight plastic car parts.

The high requirements for plastic materials in the automotive industry are based hereon. Facing competition with metals, plastics have to show a high thermo stability, i.e. at high temperatures the dimensional stability of plastic moulding compounds should exactly remain the same. Car parts and bumpers are not allowed to deform under solar radiation and motor heat. Further on, the resistance to mechanical stress is important.

In order to meet the multi-fold requirements to plastic products, composite material has been developed from the beginning of the plastic technology area. The plastics are reinforced by incorporating mineral fillers or fibres. However, in order to achieve suitable properties, 20 to 60% of mineral fillers such as talc, kaolin or calcium carbonate have to be added, which also increases the weight of the material.

Nanotechnology offers the chance to realise a high mechanical stability at a very low filler concentration when incorporating highly effective nano fillers.

Although nanotechnology is subject to a revival one should not forget that nano filling material has a very long tradition in the plastic industry. For many centuries carbon black has been applied for the improvement of rubber. Worldwide some hundred of thousands of tons of carbon black are used for the production of tyres.

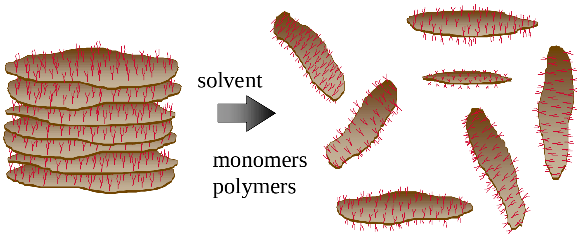
At the end of the eighties, the Toyota Research & Development department developed a completely new concept for the improvement of plastic parts for the automotive industry with the help of nanocomposite fillers. The Toyota researchers hereby applied a clay mineral which has been used in industry for more than 100 years: bentonite.

Bentonite consists of the mineral montmorillonite (60 – 95 %). Montmorillonite belongs to the so-called layered silicates representing the main component of clay minerals.

Its very good swelling capacity in water is a special characteristic of montmorillonite. Water molecules can easily diffuse in the layers of montmorillonite which is homogeneously dispersing in water in the shape of extremely thin nm-sized plates.

Now a very similar concept is followed-up with regard to polymer nanocomposites based on these natural layered silicates. Instead of water, the polymer should diffuse between the silicate layers, disperse them and finally be homogeneously distributed in a plastic matrix in the shape of nm-sized thin plates. However, to achieve this, it is necessary to organically modify the surface of bentonite and thus guarantee the complete dispersion in the plastic matrix.

Exfoliation of organic modified montmorillonite in monomers and polymers



The Toyota researchers aiming at the production of an improved polyamide material used a water soluble monomer of the polyamide for the organic modification of bentonite. The entire available silicate surface was thus modified with amino dodecanoic acid in an environmentally friendly process.

Considering the fact that bentonite shows a specific surface of about 700 m²/g after a complete dispersion, it is becoming clear that it is necessary to modify bentonite with 20–40 % of these organic "intercalation components". Mostly, conventional fillers such as calcium carbonate or kaolin are coated with less than 2–3 % of a suitable additive in order to achieve a better workability during compounding.

In the meantime, the development of (in addition to polyamide) suitable nanocomposite fillers on the basis of layered silicate for a variety of technical important polymers has been successful.

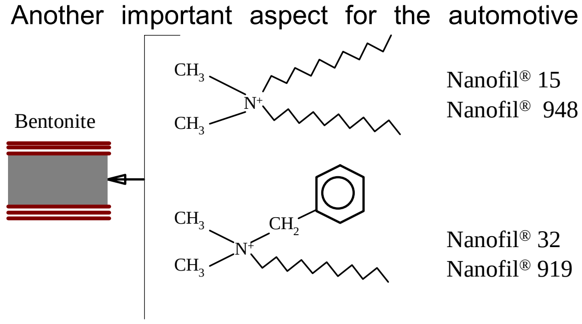
When starting the polymer nanocomposite development, nanocomposite fillers were incorporated into the polymer matrix only during polymer synthesis. It speaks for itself that this technology was originally only used by polymer producers. In the meantime, the development of suitable process technologies has also been successful. According to these technologies, nanocomposite fillers can be incorporated into the plastic material like conventional fillers via compounding processes. This technology has thus become available to all compounders and even plastic part processors.

Contrary to conventional layered fillers like kaolin, talc or mica, the typical thickness of nanofillers is 10 to 50 times smaller. The diameter of the fully exfoliated nanofillers varies between 100 and 500 nm at a layer thickness of only 1 nm. This special structure of the layers results in an extraordinarily high
aspect ratio of more than 100.

The high aspect ratio makes nanofillers superior to all other conventional layered fillers or short glass fibres. The very low particle size and the high aspect ratio yield an extraordinary improvement of the properties in a wide variety of polymer materials. This improvement of the properties may be reached with a very low concentration of nanofillers.

The density of the polymers reinforced with nanocomposite filler is only slightly higher than the unfilled polymers. This leads to a definite weight advantage especially in the area of automotive applications.

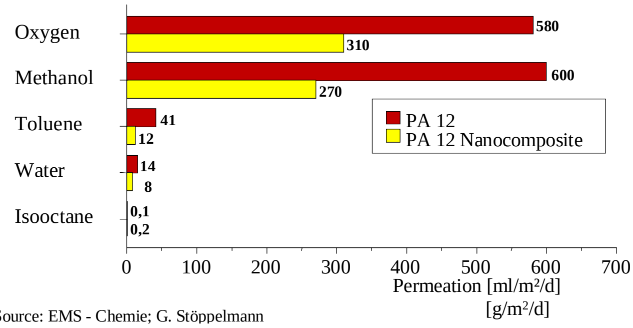
Another important aspect for the automotive



industry is the dimensional stability of plastic parts at high temperatures. This is particularly important in case the corresponding plastic parts are used in the direct environment of the motor. In contrast to conventional fillers, it is possible to increase the thermo stability of polyamide by about 50 °C with nanofillers. Only a few percent of nanofillers are sufficient.

One of the most remarkable characteristics of plastic nanocomposites is the unusual barrier behaviour towards gases and liquids. In case the nano-sized silicate layers, which are finely dispersed in the plastic are parallely orientated –which is successfully done in conventional film production, they will form a barrier for that material that is having an effect on the composite. As a result, the permeability for oxygen, carbon dioxide, or even water steam can be reduced by more than 50 % by adding only 2 weight % of nanocomposite fillers. A lot of applications are therefore expected for food packaging.

Permeation of different gases by Polyamide 12



Source: EMS - Chemie; G. Stöppelmann

Even in the automotive industry nanocomposite technology can be used to develop a zero-emission-car. Nowadays, a car is loosing a part of its fuel via diffusion through fuel lines and plastic tanks. It is the object of present co-operations between additives producers, plastic producers and the automotive industry to improve the fuel barrier of tanks and fuel lines by special plastic materials applying nanotechnology. The first results are very promising.

The high inflammability of plastic material contrary to metallic or ceramic working material is a disadvantage. Even by adding special flame retardants it is not possible to prevent various plastics from inflammability. In general, these flame retardant additives help to lower the inflammability, prevent the flames from spreading and limit smoke development. This makes it possible to apply plastics even in those fields where inflammability of plastic cannot be excluded.

However, some recent large fires have shown that flame retardant agents are subject to criticism. In case of fire, the highly effective halogen containing organic flame retardant agents generate caustic or toxic gases. In addition, these flame retardants lead to a higher smoke density.

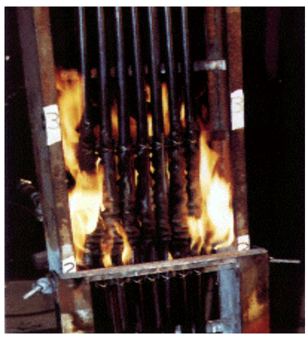
Nowadays, nontoxic flame retardants, such as Mg- or Al-hydroxide are available and meet all toxicological requirements as well as those corresponding to the environment. Unfortunately, these hydroxide flame retardants have only a comparably low effectivity. As a result, plastic material, which is to be correspondingly a flame retardant, has to be filled with about 50 – 65 % of these hydroxide flame retardant agents. However, mechanical properties are reduced while specific weight is increased.

Nanocomposite fillers offer the chance to clearly reduce this amount of hydroxide flame retardant agents, still meeting the flame retardant requirements. The extremely fine particle size and the extraordinarily high aspect ratio of bentonite nanocomposite fillers have the effect that a three-dimensional network of inorganic silicate layers can be built up in the plastic matrix with only a few weight percents of nanofiller. In case of fire, this inorganic network assists the formation of a strong carbon crust. This crust prevents the burning polymer from dropping and the fire can thus not spread. Moreover, it has been found out that smoke density can be reduced when adding nanocomposite fillers; which could be very important for survival in case of fire.

In many years of co-operation in research and development, Kabelwerk Eupen AG and Süd-Chemie AG succeeded in using the technology for the production of flame retardant electrical cables. Since the beginning of 2002 these flame retardant cables have been marketed.

The objective of another research co-operation between Siemens AG, Prof. Mülhaupt from the Freiburger Material-forschungszentrum and Süd-Chemie AG is to reduce the inflammability of this plastic material, which is applied in electrical engineering. Possibilities are being traced to find a halogene free flame retardant agent for important thermoplastic material which industry is demanding.

Flame Retardancy Test UL 1666 for cables



This project is financially supported by the German Federal Ministry for Education and Research.

In the framework of European cooperative projects, new fields of application for plastic nanocomposite technology are intensively developed. In one of the cooperative projects financed by the European Communities in which producers of polymer additives, compounders and end users of plastic are participating, new processing technologies are developed making it possible to produce cheap plastic nanocomposite materials. Those cooperative projects are helping the European industry to compete on the international market with regard to nanotechnology. Especially in the United States and in Japan, a lot of money is spent on nanotechnology research.

First „nanofilms“ have become commercially available for packaging technology. Three years ago, Bayer AG already produced a polyamide film for packaging purposes; in doing so, they succeeded in improving the oxygen barrier by 50 %. In addition to that, this polyamide film shows an improved transparency in comparison with the unfilled film. Even this characteristic, which was not expected to appear, is a result of the extremely low particle size of nanocomposite fillers. These particles are so small that they cannot interact with light; as a result, they are invisible to the eye. In Japan and in the United States similar packaging films are commercially offered with nanocomposite fillers based on bentonite, too.

Since we are only at the beginning of the industrial commercialisation of nanocomposite technology it is extremely difficult at the moment to estimate future market chances for this technology. However, considering the fact that the total plastic fillers market shows a potential of more than two billion Euro you are able to estimate a market potential based on this figure.
In case we are able to enter only a few percent of this market we are talking about sales amounting to a few million Euro.

Nanocomposite fillers based on natural bentonites are even nowadays a very good example for solving the problem how to find completely new markets for very old products – bentonites have been used in industry for more than 100 years – with the help of consequent research. However, there is a clear need in doing research and development in order to be able to use plastic nanocomposite technology in many fields of application.

The market for nanocomposite fillers has to be developed via co-operations between producers of polymer additives, compounders and end-users of plastic. It is necessary to establish a cooperation between public research institutes and industry as soon as possible to achieve a rapid market realization. For the first time nanocomposite technology is opening the door to the growing market “plastic material” for the traditional European bentonite industry.