Ceramics and Society
R.J. Brook (Editor)

RELATIONS BETWEEN MAN AND MATERIALS

G Petzow
(Max Planck Institute of Metals Research)

All of us are aware of the rapid changes in our world caused by scientific discoveries and technological developments – in some way comparable with the heroic discovery done by Christopher Columbus 500 years ago.

In our time scientists and technologists contribute decisively to our modern society and have to master not only the advantages but also the disadvantages of present and future discoveries and technologies. This is in full accordance with the words of Albert Einstein: *"Awareness of the human being and his fate should always be the ultimate concern in specialized scientific endeavors. One should never lose sight of this among all diagrams and equations"*.

Since many of us are scientists or technologists more or less concerned with materials in some way, I would like to focus in my presentation especially the role of materials in the socio-economic-context of technology, especially in view of the increasing meaning of the ecological situation.

Personally I am deeply convinced that scientists must not only merely invent advanced materials and technologies, they also must accept the responsibility for engineering them in harmony with the demands of ecology.

Between man, materials and technology has been a durable interplay during millions of years. The base of progress is an unalterable, interconnected three-way relationship as simplified and shown schematically in Fig. 1 (Petzow, 1989). In this interplay man is the decisive partner, of course. Materials and technologies are ambivalent. They are, a priori, neither good nor bad. Only man decide about their application.

As shown in Fig. 1, population grew by a factor of hundred in about 100.000 years: 100.000 → 10 Mio.. In about less than 6.000 years (4.000 BC → 1.820 AD) it grew again by a factor of 100 to 1 Billion. And this despite catastrophes, plagues and desciminating wars.

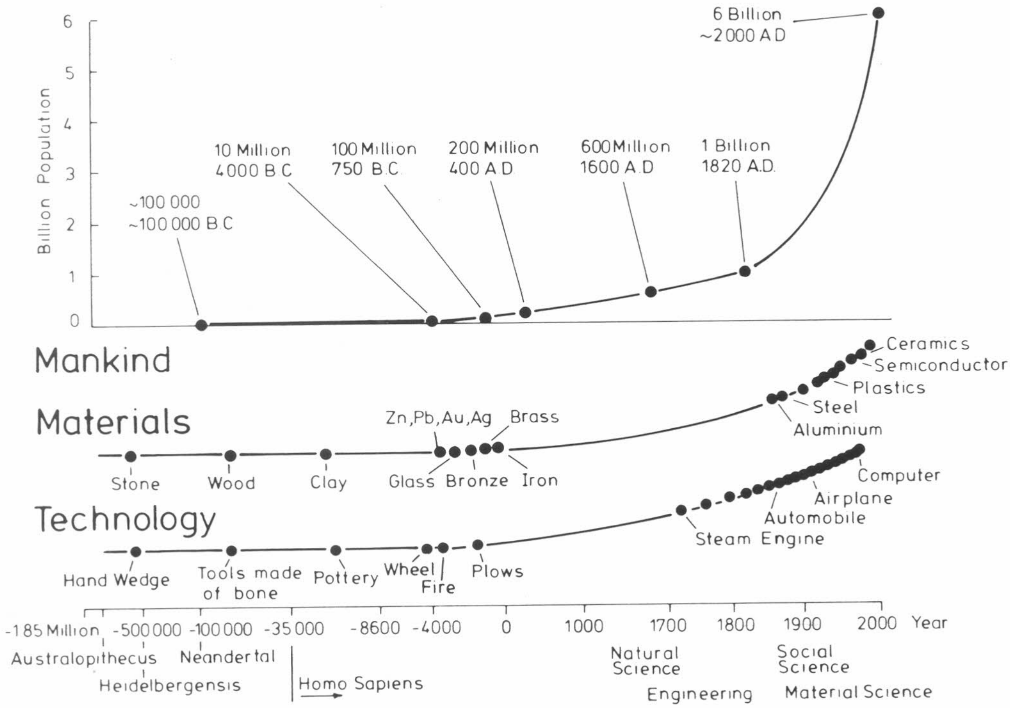

Fig. 1 The evolution of man, materials and technology

Today there are about 5 billion people on earth and the doubling rate is only 33 years. Accordingly, it is possible that, in a not quite 200 years time, there will already a factor of hundred increase, that means 100 billion (10^9) people on earth.

Through his materials and their use in technical devices and processes, man has made earth his subject. Materials are one of the oldest cultural assets. Historical eras named after materials and new materials often had far reaching consequences. One can expect the discovery of more materials in future. Every chemical compound and every alloy is a material that could potentially revolutionize our life to the extent that first stone tools changed the life of early man. Materials turned into tools, devices, machines, houses and streets. Revolutionary technological developments have followed in quick succession in modern times.

The rise of the evolutionary curves for materials and technology in Fig. 1 includes the number of new discoveries. For reasons of clarity not all events are shown: printing, radar, telephone, satellites, superconductors, nuclear fuels, etc., are left out.

It has taken a long time for developments to reach the current rate. And the question arises, whether the steeply increasing population curve and the pace of technological innovations really present true progress!

There was a first warning twenty years ago by the Club of Rome. Its members predicted a catastrophic situation early in the next millenium. In case the conditions 20 years ago would remain, the increase of population would cause a need for more food, more industrial production, more energy and raw materials and as a consequence an increase of pollution. All that would have yield to an unballanced situation on earth in the next century creating the catastrophe. But fortunately today, 20 years after the prediction of the Club of Rome, Donella and Dennis Meadows (Meadows, 1992) have made a new prediction with updated informations. They realized that the situation has changed to a more positive side:

- Population rate is decreased since 1971 from 2.1 % to 1.7 % per annum.
- The energy consumption became more reasonable.
- Better materials and technolgies are available.

Therefore, the catastrophe is shifted further to the future and there is even hope for avoidance.

Donella and Dennis Meadows' prediction expresses the first success of ecological renewal, which will more and more influence our life and our thinking.

A similar situation to present times has happened in history already twice: around 4.000 BC when early man settled from a nomadic behaviour as hunters and began with agricultur. And then around the middle of the 18th century: the Industrial Revolution. In both cases materials and technologies have reached a standard which allows such drastic changes in human being. We are now obviously in the beginning of a third renovation: The Ecological Renewal. And again, there is no alternative to technology. Ecology can not be realized besides technology and not against technology. But there is only one choice for industry and that is to adapt ecologically (Huber, 1985). New materials and innovative technologies offer a means just for that. There does not seem to exist another solution of our ecological problems than a broadly distributed development of technologies and materials.

Materials are prerequisite for technology. But even today materials are mostly taken for granted - they are self evident to most people.

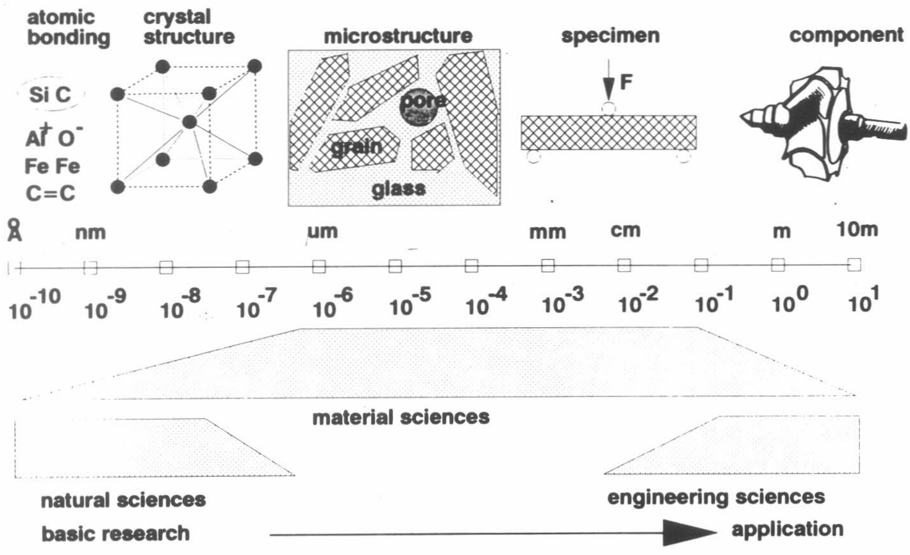

Fig. 2 Materials science explores the structures of materials from the atomistic to the microscopic dimensions

Until the present century new materials were found fortuitously during tests or technological processes. The manufacturing of those materials depended on the ability of craftsmen and traditional methods. In those times, empirical and practical knowledge were far ahead of basic scientific understanding.

The scientific study of materials only took place at the beginning of this century, with the understanding of the atomic structures of matter.

There are many classes of engineered materials, metals, ceramics, polymers, etc., with manyfold, very different properties, which are intensively studied, initially strictly separated in the classes. Since 40 - 50 years, however, the overlap between these classes has become apparent. Materials science as a scientific discipline began to grow. As expressed in Fig. 2 materials science is bridging natural sciences and engineering sciences or in other words basic research and application. Materials science is supported in many cases by concepts of chemistry, physics and cristallography. The considerable success of materials science was its explanation of empirical findings accumulated in large numbers and the resultant improvements and extensions. The great significance of materials science in technological progress is that it can lead to a basic understanding of internal structure, so that new materials can be invented and taylor-made for specific applications, literally by microstructural and molecular design.

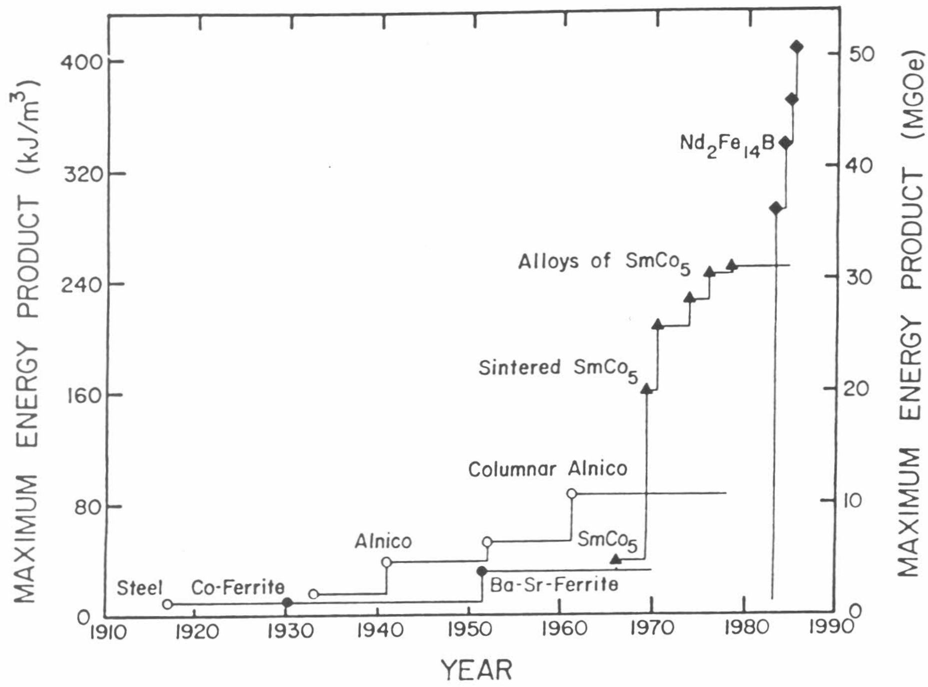

Fig. 3 Evolution of the maximum energy product of permanent magnets

As is expressed schematically in Fig. 2 there are tremendous dimensions to master, from the nanometer scale to macroscopic sizes. At present the main domains of materials science are regions of micro- and nanostructure.

In recent years there have been many technological breakthroughs via advanced materials. Those materials have a key position since they enable new technologies, not possible before, because of the lack of proper materials. Only a few examples of recent breakthroughs are demonstrated by Figs. 3, 4 and 5. All these developments expressed by Figs. 3 to 5 are typical examples for real progress with striking influence on the ecological behaviour.

Especially convincing to be seen is the ecological advantage in an actual industrial development which might come into mass production in the next few years, namely the ceramic valves for automotive engines made of silicon nitride alloys. Compared to metallic valves they are lighter (two thirds) and have a better wear behaviour yielding to higher performance, lower fuel consumption and lower exhaust emission (Hamminger, Heinrich, 1993).

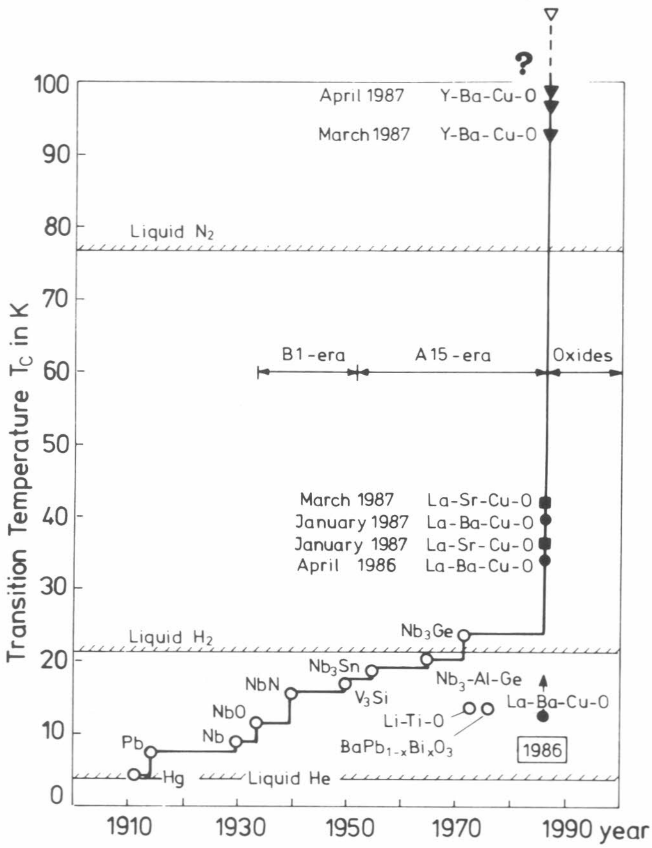

Fig. 4 Historical development of High-Tc Superconductors

All these examples demonstrate quite clearly: materials science can help to ensure that the technological evaluation is on the right track: Not only the use of our resources and energies is enhanced, but also our environment is better protected. In short: With less resources, less energy and a smaller environmental impact we must attempt to make today's highest standard of living accessible to all people, based on more intelligent, innovative materials and technologies. In very short: More with less (Altenpohl, 1980)

After all the recent developments of new materials, the question as to the potential of further materials arises. Can we hope for significant new contributions, especially if we consider the great multitude of materials already available?

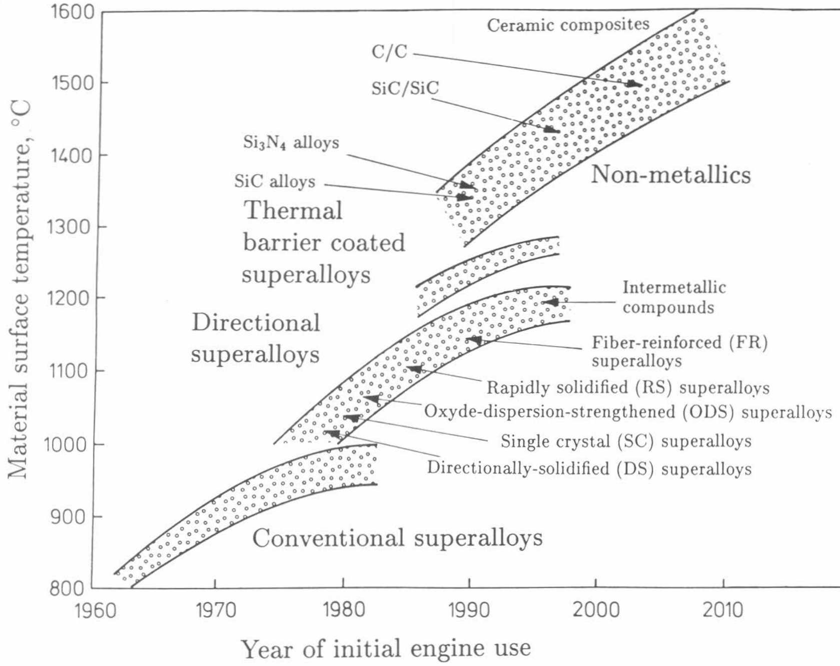

Fig. 5 Evolution of high-temperature materials

The answer is straight-forward: YES.

In fact, potential materials are in abundance and the possibilities of combining and varying elements are almost unlimited even though there are just over 100 elements. The following considerations may help to clarify this:

Elements can be mixed or alloyed respectively and combined to systems, for instance the well-known iron-carbon system, which involves many carbon steels and cast irons. Let us consider 86 of the 100 or so elements we know, and ignore inert gases and the trans-uranic elements. If we combine these 86 elements to binary, ternary, quarternary systems and so on, up to the 86-element system, the total number of possible systems comes to as many as 7.7×10^{25}!

In Fig. 6 the number of possible systems is plotted as a function of the number of elements N. This can be drawn only on a logarithmic scale, otherwise the ordinate would extend to the Milky Way. We have only 86 unary systems (the elements), 3.655 binary systems, more than 100.000 ternary systems and so on and the maximum of 6.6×10^{24}

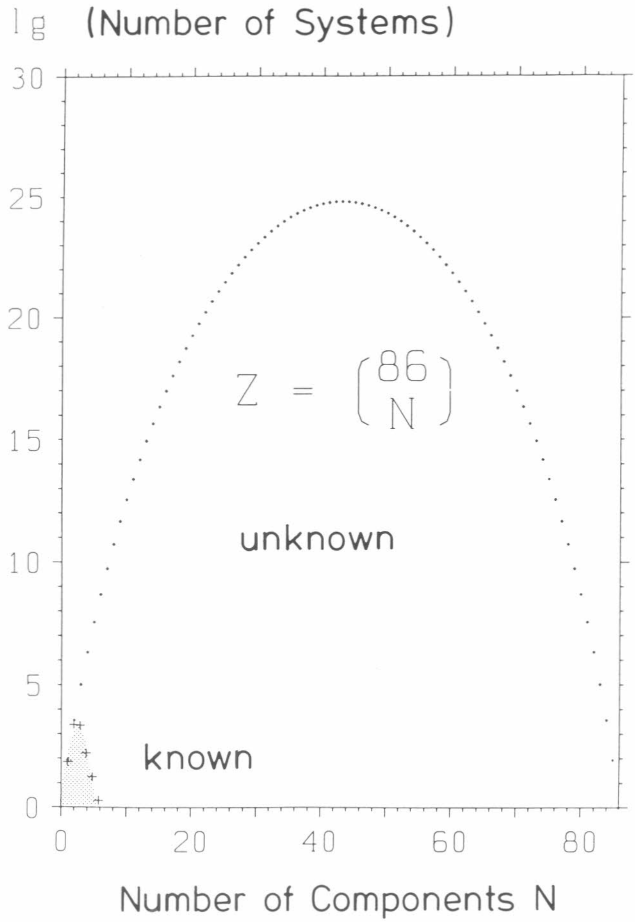

Fig. 6 The "mountain of materials"

systems is reached with 43 elements. Beyond this maximum the number of possible systems decreases and finally only 1 system with all 86 elements exists (which contains all other systems as subsystems).

On the other hand, the number of systems investigated decreases steeply as the number of components increases. Altogether about 8.000 systems are known to date, most of them only partially. This is marked by the hatched area in Fig. 6. This area represents all known materials. The ratio of known to possible systems is as small as 10^{-22}.

This mountain of materials shown in Fig. 6 is hardly accessible in reality and represents a huge reservoir of materials. Despite the numerous combinations of elements used in today's materials, a much larger multitude of unknown possibilities remains. Among these could be numerous technological material combinations, which some day could play a role similar in importance to today's steels, superalloys, advanced ceramics and so on.

The dimension of this reservoir increases if one considers that an element system containing many technical alloys is counted only once in this plot. Further multiplication results from the fact that neither element modifications (e.g. graphite, diamond and carbon) nor metastable states, e.g. glasses, have been included. Thus, an incredible abundance of possible materials is available. Buried in the nearly inexhaustible manifold of potential materials is a formidable task and nevertheless a great challenge and adventure for the materials science community.

With less resources, less energy and a smaller environmental impact, based on more intelligent, innovative materials and technologies, materials science can contribute significantly to an already beginning change in industrial culture. A change that will lead to a socio-economic and ecological future with man in harmony with his materials and his technology.
Not a revolution is necessary to reach the goal nor a "back to nature"-idea, but just some new thinking and adaption.

Or expressed in the simple words of Linus Pauling:
"*If man had as much sense as reason, things would be a lot simpler*"

References

- Petzow, G., 1989. In High-Tech Ceramics, Viewpoints and Perspectives, Kostorz, G. (ed.), pp. 1-15, London: Academic Press.
- Meadows, D. and Meadows, D., 1992. Die neuen Grenzen des Wachstums, Stuttgart: Deutsche Verlags-Anstalt.
- Huber, J., 1985. Die Regenbogengesellschaft, pp. 175 ff, Frankfurt: S. Fischer Verlag.
- Hamminger, R. and Heinrich, J., 1993. Spektrum der Wissenschaft Januar, 114-116.
- Altenpohl, D. 1980. Materials in World Perspective, pp. 200 ff, Berlin: Springer Verlag.