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Teaching materials science and engineering

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Abstract. This paper is written with the intention of simulating discussion on teaching materials science and engineering in the universities. The article illustrates the tasks, priorities, goals and means lying ahead in the teaching of materials science and engineering for a sustainable future.

Keywords. Teaching materials science; excellence in science; dissemination of R & D.

1. Introduction

The notion of excellence in science is universally attributed to the "pathfinders" – those whose distinction lies in their research work: New results, new interpretations, new research techniques are the driving force of scientific progress. This holds in a general sense as well as for the individual scientist. Still, while scientific results need to be accepted and verified by other, independent research, its general reputation is linked to the successful transfer of the "state of the art" to the minds of younger collaborators and students, that is to say: to teaching. Teaching is of crucial importance to the future dissemination of research and development capacity in any region of the world.

This article undertakes to discuss tasks and goals in teaching materials science and engineering (MSE), that have evolved under actual conditions in the last decade. Special reference is made to the situation in India, though the author is conscious of the limitations of being a foreigner, who can only hint about what he considers essential, while the detailed structure has to be elaborated by the active community of researchers and users as well as by the political representatives responsible for the welfare of the nation, with due reference to its history and tradition, its natural resources and its position in the world.

2. Metals and other materials

In this work, we avoid distinguishing between "metals" and "materials", since metals and their alloys are, in fact, materials. There exist, however, other materials, too, characterizing our professional life. There are ceramics for both structural and electrical (or electronic) use, polymer materials ("plastics") for structural applications (like packaging), and—in a growing measure—for active electronic functions.

On a worldwide scale, current research work proposes new materials at a breathtaking speed. Some of them present hope for rapid practical application ("emerging" materials), others are more to be looked at as a contribution to the general knowledge of the solid state. Studies of the latter type are by no means useless, even if authors of fundamental research reports are often too rash in announcing their objects as "interesting candidate materials" for this and that application. They are thereby underestimating the enormous effort which has to be invested in processing, shaping, testing and standardising before these "materials" can be accepted for safe practical use, and before an equilibrium is achieved between availability, market prize and production cost. The latter argument is an important one also for teaching: on the one hand, the student is entitled to a realistic scenario instead of fantasies. At the same time, it is important to motivate young people by demonstrating that materials science is still full of vitality, progress and new challenges.

Recently, the materials world has been truly enriched by entirely new techniques: coatings and surface modifications have come to form a discipline of their own. The principle of fibre reinforcement has been extended to nearly all material classes. With the aid of numerical methods, compounds and composite materials can now be “designed to order”, by combining them with one another or with natural components, such as wood or textiles. Numerical calculations also help in selecting the optimal material or the treatment for a given application under many interacting criteria. Likewise, energy input during processing has developed many different techniques from very slow to ultra rapid (shock) mechanics, to lasers and electron beams. Materials testing, in particular by non-destructive and by computer-assisted methods, has become even more important as people become more sensible to accident risks.

Indian scientists have quite a share in these modern developments. The country owns well-equipped research centres within the Indian Institutes of Technology (IIT’s) and the universities, as well as other R&D establishments of the Government of India, notably attached to nuclear energy science and technology and defence. Furthermore, private industry can boast of excellent laboratories and “think tanks” in various areas from steel-making to electronics.

3. Knowledge and understanding

The foregoing remarks on the diversity of materials indicate that it would be of no avail to “infiltrate” a young student with detailed knowledge of all those plain and alloyed steels, nonferrous metals and their alloys, oxide and nitride ceramics, carbon and glasses, graded, textured, nanocrystalline, noncrystaline and quasicrystalline matter, natural products like rock or wood or textile fibres – not to forget their countless combinations.

Rather, he or she should acquire a broad overview of the multiplicity of materials and the essential differences between them. Thus, they will get a feeling for their properties and also for the typical process roads, for equipment, manpower and energy requirements used in their manufacture. This is wise, last but not least in order to gain additional professional flexibility in the sense of being able to cope with a rapidly changing economical or social environments, as is more and more the case in our “globalized” world – where your lab or firm may, as of next week, have another director or proprietor. After such a period of general adaption, the student will wish to focus for some time on one material or one technique with the goal of building up solid methodical expertise.

It makes good sense to conclude that the goal of academic teaching should not be seen in encyclopedic knowledge. For this purpose, the future holds various and very well-adapted means. Printed encyclopedias (general and specialized), scientific journals, preprints on the internet, conference proceedings, rapid international abstract services. Thus, many channels contribute to the dissemination of research news, and the efficiency and intensity of this kind of information network is in full development. To duplicate it by traditional academic teaching in classrooms tends more and more to waste the time of teaching personnel and that of students. Apart from the steadily growing volume of knowledge, we should keep in mind that students try to earn some money by "jobbing", while teaching staff most often has research and consulting responsibilities in parallel.

What is more, objects of academic teaching need continuous reflection with the aim of "streamlining" studies. The related question of whether these should be limited to a given number of years is certainly important and serves the international exchange – like all standardization measures. This issue is dependent on the secondary school system and has intricate consequences for the labour market. The same holds for "refresher courses", imparting necessary knowledge to engineers as they grow older and have to face competition by the next generation – certainly a serious responsibility for the university system. In fact, the University (in a broad sense) can be regarded as a very large integrated system transferring skills and knowledge to different groups of the society. Such an issue should, therefore, be discussed on a national basis. Only a national platform is suitable to appreciate the value of "studentship" – the wonderful feeling of the young adult to be free not only for professional training, but also for new horizons in his or her general culture, philosophy and religion, sports, personal relations, social links, citizenship, duty and adventure . . . values to be defined in the context of regional and even local conditions and family background. A Hindu, a Muslim, or a Christian will give different answers to this question of a student's life – and fortunately so. The student is a human being and not a robot.

In the above-mentioned sense, the key to efficient studies appears to be understanding rather than knowledge. To understand why aluminium is more expensive than steel, why some alloys tend to be brittle while others may be plastically deformed, why some materials are conducting and opaque, others are insulators and transparent, why holography gives different information on a faulty structure than do X-rays – this should probably be the clear goal of academic studies, being evident from all subjects of teaching. To understand the thermodynamic fundaments, the resulting microstructures, the properties, and the processing routes of a few binary systems is more essential than the ability to draw 25 binary phase diagrams, which can be looked up in a database.

Understanding elementary laws – being able to develop a simple model of a complex behaviour – use a computer to calculate this model numerically – interpret the plausibility of the results – select the best technique to experimentally verify the outcome – here is the core competence which a young engineer would like to offer to society. It may be that some of the lecture courses given today are all too similar to those which we heard from our teachers, 20 or 40 years ago. The use of a "power point" projector alone is no guarantee for modern teaching. But competition will promote progress!

4. The impact of life sciences and information technology

Since the glorious days in the period of about 1970 to 1990, the role of MSE on the international science stage has changed: it is no more the radiant favorite of governments, of funding agencies, industrial policy makers – not even of students. In some places, student enrollment has dropped to the extent of causing quite some concern. Certainly, on a global scale, the situation is more positive rather than dramatic. In those regions which have been particularly hit by "student shortage", faculties and professional societies have started "marketing" actions, industry and governments have become aware of the growing risk of failure to find sufficient numbers of young engineers, and young people have changed slightly their preference for becoming medical doctors, corporate lawyers or "Chief Executive Officers". Slowly, the ranks of young materials engineers has begun to fill up again. Still, it is obvious that MSE – in need of new electron microscopes, powerful computers, advanced mechanical testing machines, vacuum furnaces and so on – must be truly visible on the market in order to attract both manpower and funds.

During this time, yet another serious competitor appeared – under the label of science: the fundamental sciences of physics, mathematics, chemistry and biology proved and demonstrated that they are advanced and powerful enough to adopt vast fields of nature for application. It is thus that we encounter not only Materials Science, but also "Earth Science" and "Life Sciences". The latter ones have obtained particularly wide attention and – e.g. in the USA and Europe – affluent funding, research activity, publicity and growth of university departments. This was, in some places, even more pronounced than the progress of Information Technology (IT), based on computer and solid state science. Indeed, IT became a "master science", governing all sorts of intellectual activities which are necessary (but maybe not sufficient) to organise very large and complex entities – such as finance markets, insurance companies, airline operations, internal revenue systems, as well as macromolecules.

Concerning life science, it may be mentioned as an anecdote that the Swiss Institute of Technology in Lausanne, to which this author is affiliated, recently got a new president. Following a long row of physicists, civil and mechanical engineers, this new president turned out to be a medical doctor, specializing in research on bio-mimetic nerve-implants. Moreover, whom did he chose as his Vice President? A biochemist! Ten years earlier, this would have been unthinkable. Even now, the nomination caused quite some nervousness among engineering professors. The government, however, maintained a firm stand. Today, the choice of the new top level in this university is appreciated by nearly everybody and judged as intellectual enrichment.

5. Challenge vs responsibility

The remarkable echo of the life sciences may have something to do with the personal interest of every human for his physical integrity, for diseases and health. Cells and blood vessels, nerve signals and virus attacks, cloned sheep and manipulated food trees are as complex or even more so than phase diagrams and dislocation cores – still, they appear to have a closer relation to the very essence of human life. A deep-rooted tendency to analyse biological problems, obviously dwells within mankind and sets guidelines towards a new way of mastering the gene spirals of nature. In the same way, the sophisticated marvels of information technology are obvious to everyone who knows to use a mobile or cell phone, a GPS system, or a simple computer. In contrast, it normally takes a lot to convince your neighbour that the entropy of microstructural defects or a gradient in the thermodynamical potential are all that important to know.

It is true that such preferences do not hold forever. We have seen the coming of astrophysics and nuclear science, TV and worldwide SD-telephone. Giant steel structures such as offshore platforms or wide-span railway bridges capture our imagination. The relative impact of these problem areas is changing with time. Nevertheless, being engaged in teaching materials science, it appears justified that one keeps discussing the chances for a healthy future of materials science. It would certainly be the wrong trend to go back to artisanal techniques and experiences which are transferred from father to son. MSE is difficult, its methods and theories have to be seriously studied. However, our justifiable interest in continued materials research calls for a certain awareness of human needs, ambitions, hopes. The statement that "everything is made of a material" and that, hence, MSE is the very basis of every other science, is not likely to find too many believers, and even international distinction and adoration of our intellectual leaders in the field may not be a sufficient goal in the minds of those who represent the opinion of the general public. Thus, beyond the fascination of new materials, we should cater to Mr. Everyman's needs – humble but essential. We should be striving to develop a branch of MSE as a science with a visible humanitarian outcome which helps to improve the quality of life of many – in high technology centres as well as in the villages. This message needs to be widely communicated, in order to create a sustained interest of the society-at-large in the science and engineering of materials. One should perhaps not waste time and effort for exotic projects – like premium wrist watches or special alloys which are only used in luxury cars of the highest price level. The competitor and at the same time the model is not in London or Zürich, but in Shanghai or Singapore, in Taipeh or Kiev.

6. Examples

Here are (in alphabetical order) a few examples to illustrate the point for necessary developments on the borderline between science and technology:

(a) Aluminium alloys, strong enough for trucks, containers, petrol tankers;
(b) agro-textiles for soil improvement, water economy;
(c) airport security systems – sensors for dangerous material;
(d) battery research for cheap, recyclable, efficient batteries of all sizes;
(e) ceramics as a technical material for irrigation, electronics, modern household technology;
(f) copper sheet for roofing;
(g) material for implants. instruments and similar materials for local hospitals and dentists;
(h) powder metallurgy – already present in India, might still be expanded;
(i) rails and sleepers (steel and concrete), welded and high-precision, for railroads; in particular for future automated city-links. Equipment for in-service quality control;
(j) repair techniques for wear of earth-moving equipment by means of welding and PVD-methods, to improve lifetime under rough service conditions;
(k) monsoon-proof, low-noise road surfaces. Electrical devices for use in very moist climates;
(l) packaging material for food and pharmaceutical industries – super-clean, laser-lettering. Re-usable bottle caps;
(m) solar energy devices for rural regions – centres which provide energy for small pumps, households, radio and TV, educational computers, small power tools. Mind that such energy will not be available all hours of the day;
(n) superconducting material for conventional electrical engineering and for future "Transrapid" trains (see Shanghai, Beijing, Corée, Munich etc.);
(o) wind energy, rural and off-shore: Light, stiff materials for blades. Storage materials;
(p) zinc refineries – as a continuation of ancient Indian technologies with modern process and monitoring technology, catering for indigenous automobile factories etc.

Surely, every reader will have complementary ideas or objections. We may stop the list at this point. It appears essential to concentrate not on enormous, land-consuming, polluting plants, but on "SME" - small and medium enterprises. They can create jobs in a short time and in high numbers. From travelling in South America, this author is well-aware of the argument that countries with a strongly rural character are not in need of jobs since they have so many unemployed and unskilled workers. However, actual development will force second thought on this argument. In 10 to 20 years, nobody will need any more the classical man with a shovel and a wheelbarrow. Skills will be used for the simplest activities – digging a hole, driving on a fast three-lane highway, distributing electricity – in automated sales, supermarkets and hotels with much less personnel than you are accustomed to now. Thus, a good education at all levels will be imperative, and this article wants to provide nothing but a few ideas and arguments to stimulate discussions among those who develop and teach MSE for a sustainable future.

7. Summary and outlook

Praise is due to all our colleagues who have contributed and continue to work on the scientific basis of solid state physics, crystallography, thermo-dynamics, and chemical process theory. Their work was and is absolutely necessary for the creation of an unfailing structure of thoughts, data and pictures describing how materials are formed by atoms.

The present article addresses a particular and nevertheless quite general issue: teaching materials science and engineering at university level at the beginning of the 21st Century. It accords priority to forming a network of relations or "laws" which allow the construction of more and more quantitative models for the physical, chemical. mechanical and biological behaviour of the multitude of existing metallic alloys, ceramics, glasses, polymers etc. This includes the range of processes necessary to transform original matter into practical and useful state and shape of material. It is necessary that in order to achieve this capacity of constructing and using models, other traditional items in the curriculum have to be reduced or withdrawn, or treated as an optional appendix.

The student – such is the argument proposed here – needs to recognize and to understand the meaning and value of notions like human labour, capital investment, cost and price, availability and reliability, testing and standardization of material. It is not further new lecture courses which are the goal, but the "spirit" of treating materials-related issues within an academic environment.