

Recent trends of applied superconductivity

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1. Introduction

In this address today, I would like to briefly outline the activities of the Laboratory of Manufacturing Technology (LMT), which I have founded in 1982 and I

am directing until today, see Figs. 1 and 2, and to exchange some ideas in the very important engineering areas nowadays, from industrial, research and academic point of view, namely *nanotechnology* and *superconductivity*.

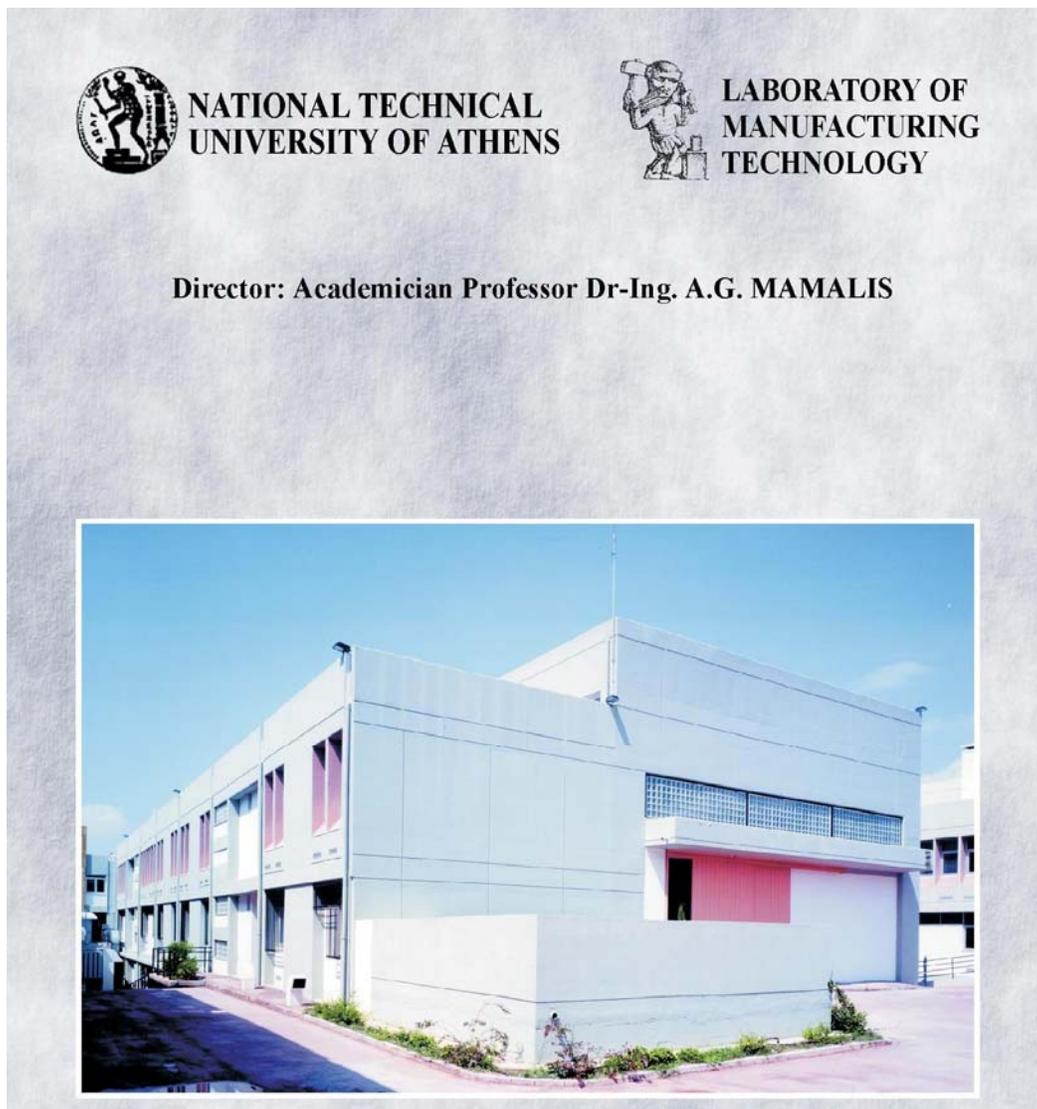


Fig. 1



The Laboratory of Manufacturing Technology of the National Technical University of Athens, located at the University Campus in Zografou/Athens, in its present form has been established in 1982 by Academician Professor Dr.-Ing. A.G. Mamalis. It covers a working area of about 3.200 m², extended to 3 floors. A great deal of education, research and industrial experience has been accumulated within it with respect to the deformation mechanics and the behaviour of advanced materials both during their manufacture and under service loading.

From theoretical and experimental research activities point of view, the Laboratory of Manufacturing Technology participates into a great number of research projects (European, national and under bilateral agreements) mainly with industrial international and national cooperation, qualified in the following areas of research:

- Theoretical aspects of plasticity and stress wave propagation, numerical modelling and simulation of processing and constitutive behaviour of materials.
- Manufacturing processes: rolling, forging, extrusion, sheet metal forming, metal removal processing, explosive cladding, casting.
- Precision and Ultraprecision engineering, Nanotechnology
- Powder processing (static and dynamic) of metals, ceramics and advanced high- T_c superconducting materials.
- Structural plasticity pertaining to the crashworthy deformation of thin-wall structures of metals, polymers, composites and bi-materials for application in the automotive, rail and aircraft industry.
- Advanced Manufacturing: CAD/CAM/FMS/CIM/Robotics/Expert Systems/Simulation.

The Laboratory of Manufacturing Technology of NTUA is well equipped with fully automated machines and instrumentation related to the various aspects of manufacturing:

Fig. 2

2. Nanotechnology/Nanostructured materials

Nanotechnology and the *tendency to miniaturization* in the manufacturing industry are related to various scientific and technological areas, like microelectronics and computer industry, robotics, biology and medicine, fiber optics, aerospace, advanced materials technology, chemical engineering and precision manufacturing. Two interlinked trends are involved, *towards miniaturization* and *towards ultraprecision processing*. *Ultraprecision processes* are already extensively applied in manufacturing industry, replacing “traditional” manufacturing methods. On the other hand, in order to observe and measure at the nanometer scale, by employing principles of physics, various new methods are used, such as *atomic force microscopy*, see Fig. 3, *laser position measurement* and *tunneling electron microscopy*. These techniques allow for manipulating objects on the atomic scale and putting an atom or a molecule on a designated location. *Nanotechnology* is perhaps today’s most advanced manufacturing technology and is usually called “extreme

technology” or “bottom-up” manufacturing, see Fig. 4.

Therefore, the design and manufacturing of *nanostructured materials*, like *nanoparticles*, having every atom or molecule in a designated location and exhibiting novel and significantly improved optical, chemical, mechanical and electrical properties, were made possible.

Especially, when *treated under shock*, they can be used as structural materials for aerospace, semi- and superconductors, catalysts and biocompatible implants. Note, that, during *shock, explosive, or electrodynamic compaction*, the powder surfaces are accelerated into the pores at high velocities, impacting each other, with frictional energy release. This leads to melting at the surface regions with the associated bonding once the material is solidified. If brittle materials are consolidated, profile fracture also occurs, leading to the filling of the gaps. Reactive elements can also be added to help the bonding process. The high-pressure state creates numerous lattice defects and dislocation substructures leading very often to localised shearing and microcracking.

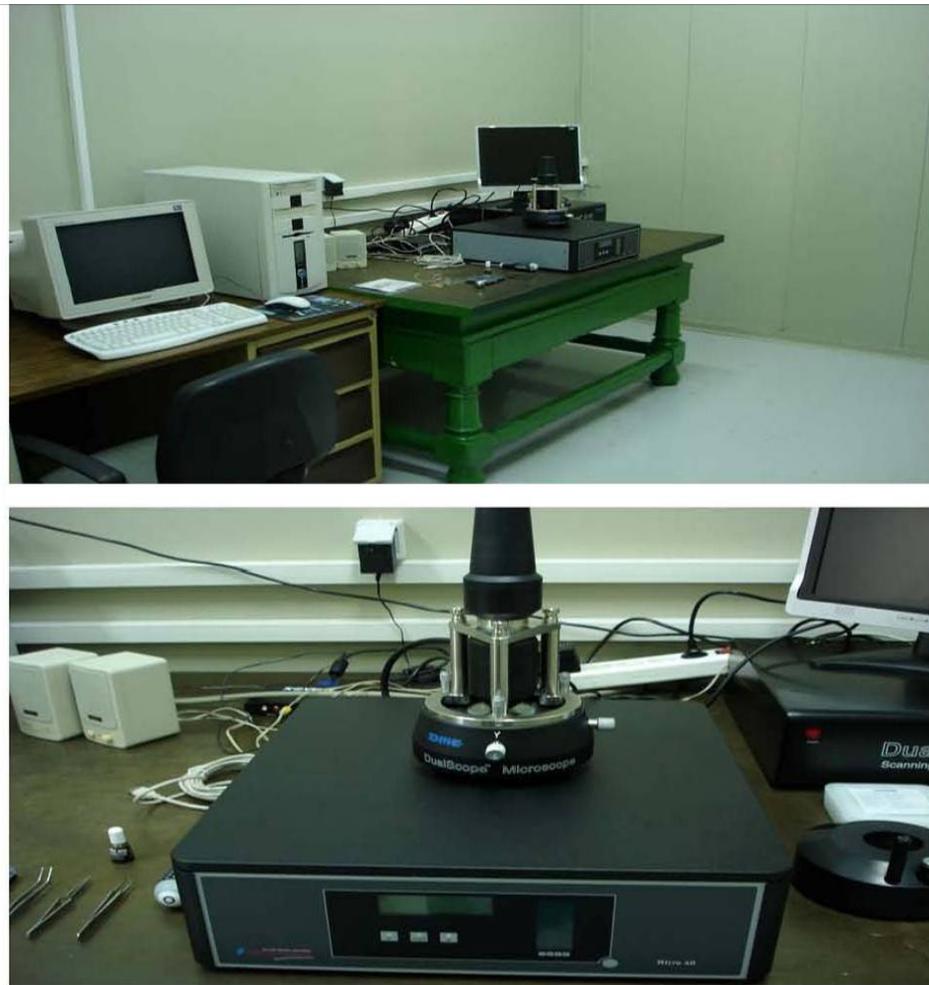


Fig. 3 Atomic Force Microscope

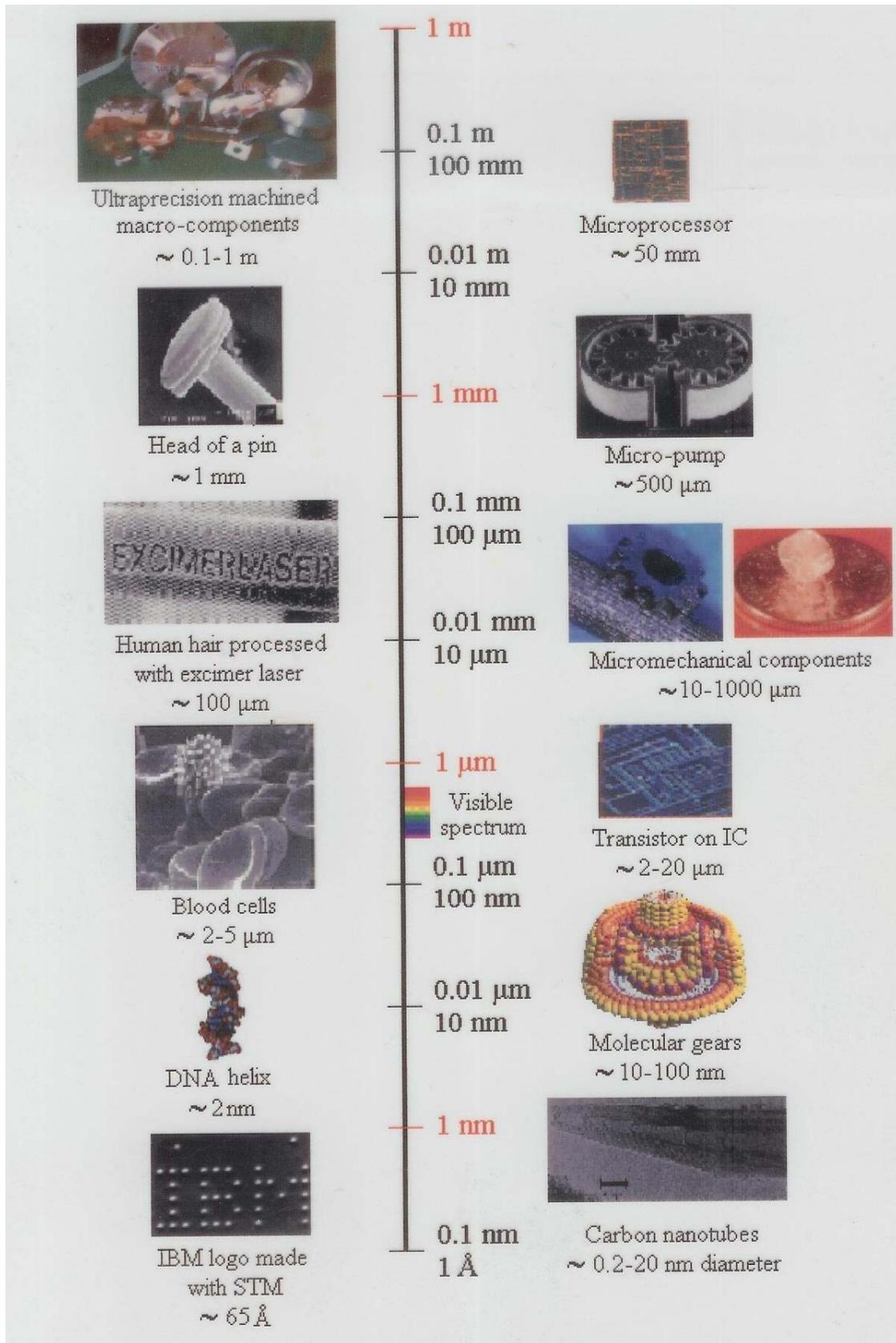


Fig. 4 Size scale and examples of micro- and nanocomponents

3. Superconductivity

The ceramic and metal/ceramic materials that present zero resistant at certain temperature above absolute zero are named *superconductors* and the related phenomenon *superconductivity*. Several industrial applications of bulk high-temperature superconducting ceramics of the YBCO, BSCCO and lower-temperature MgB_2 compounds have been developed by the author and his collaborators in

France, Hungary and Russia and, recently, in Ukraine, see Fig. 5. Using *explosive* and *electromagnetic dynamic compaction techniques*, see Figs. 6,7, and subsequent *net-shape manufacturing processes* i.e. forming (rolling, wire-drawing, extrusion and forging) and metal removal processing (machining and grinding), see Figs. 8,9, billets, rods, wires, plates and strips are manufactured, see Figs. 10,11.

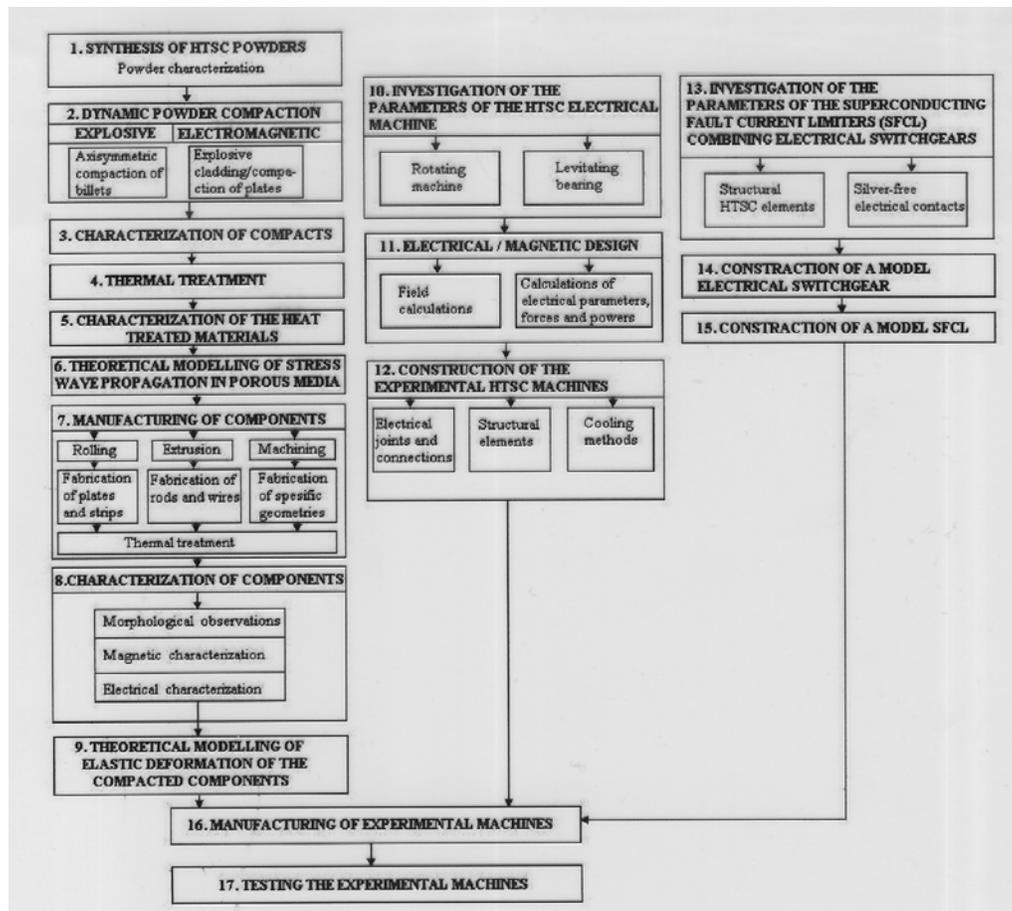
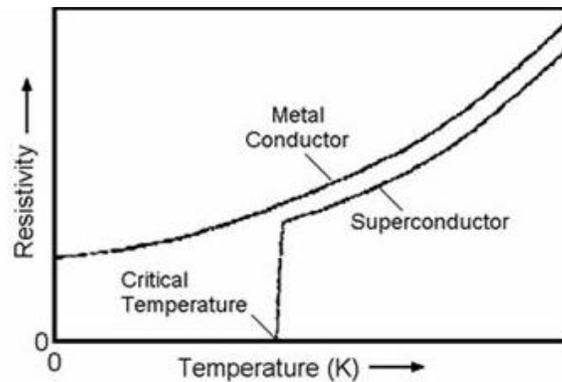


Fig. 5 Flow Diagram for Processing High-Tc Superconductors

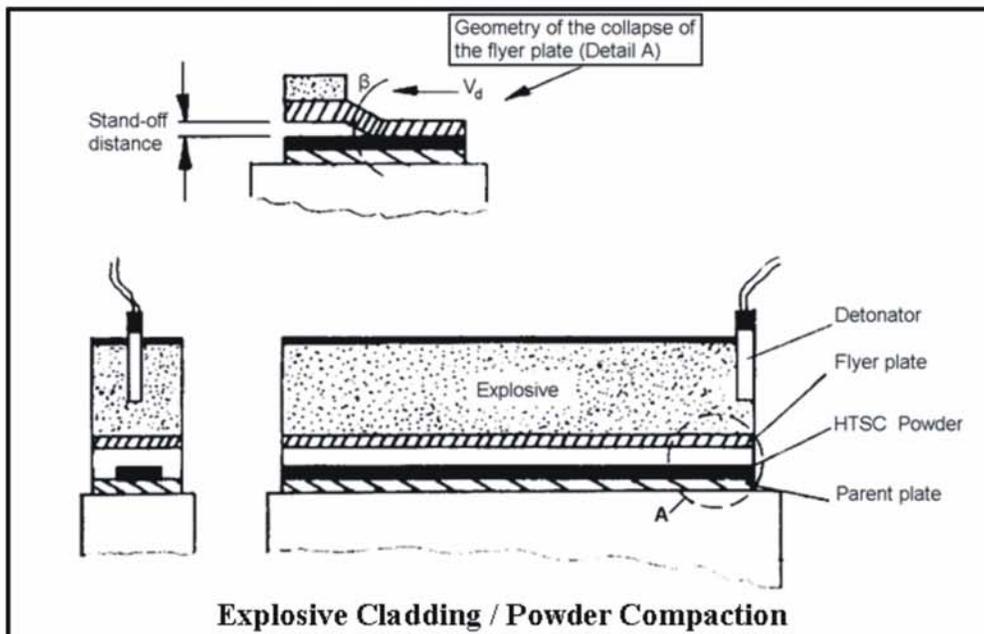
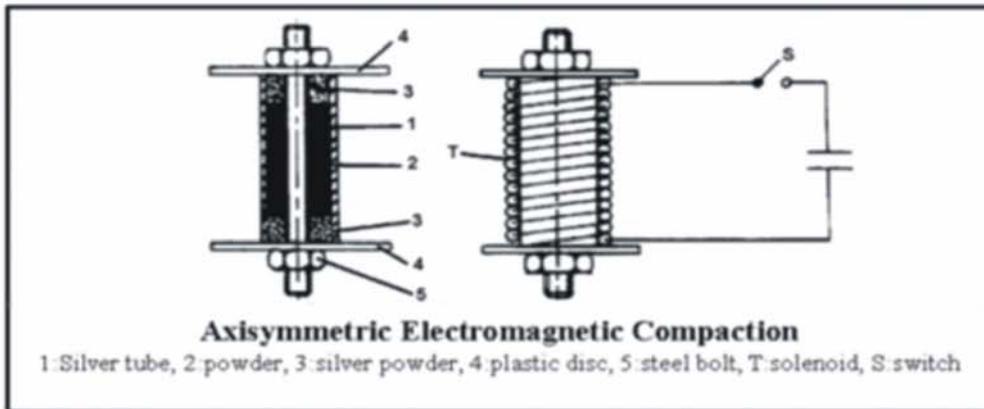
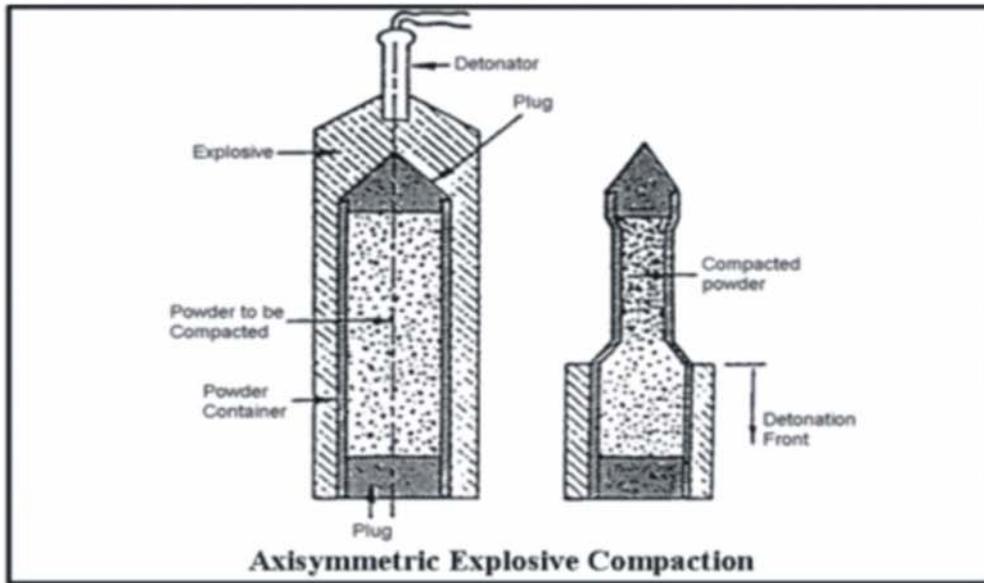


Fig. 6

- **Surface engineering/Coating**



- A shot peening / sand blasting machine for contour forming and surface treatment.
- An AGIE fixed tool electro-discharge machine (EDM).
- A METCO plasma-spray installation, fully automated, for metal and ceramic coatings.



- **High energy rate forming (HERF)**

- An electromagnetic forming machine of 30 kJ discharge capacity, for forming tubular components and sheets and for dynamic powder compaction of metals and advanced ceramics.
- An explosive chamber of 0.5 kg TNT charge capacity for explosive bulk and sheet forming, explosive welding/cladding and explosive powder compaction of metals and advanced ceramics.

Fig. 7. Existing equipment of the LMT

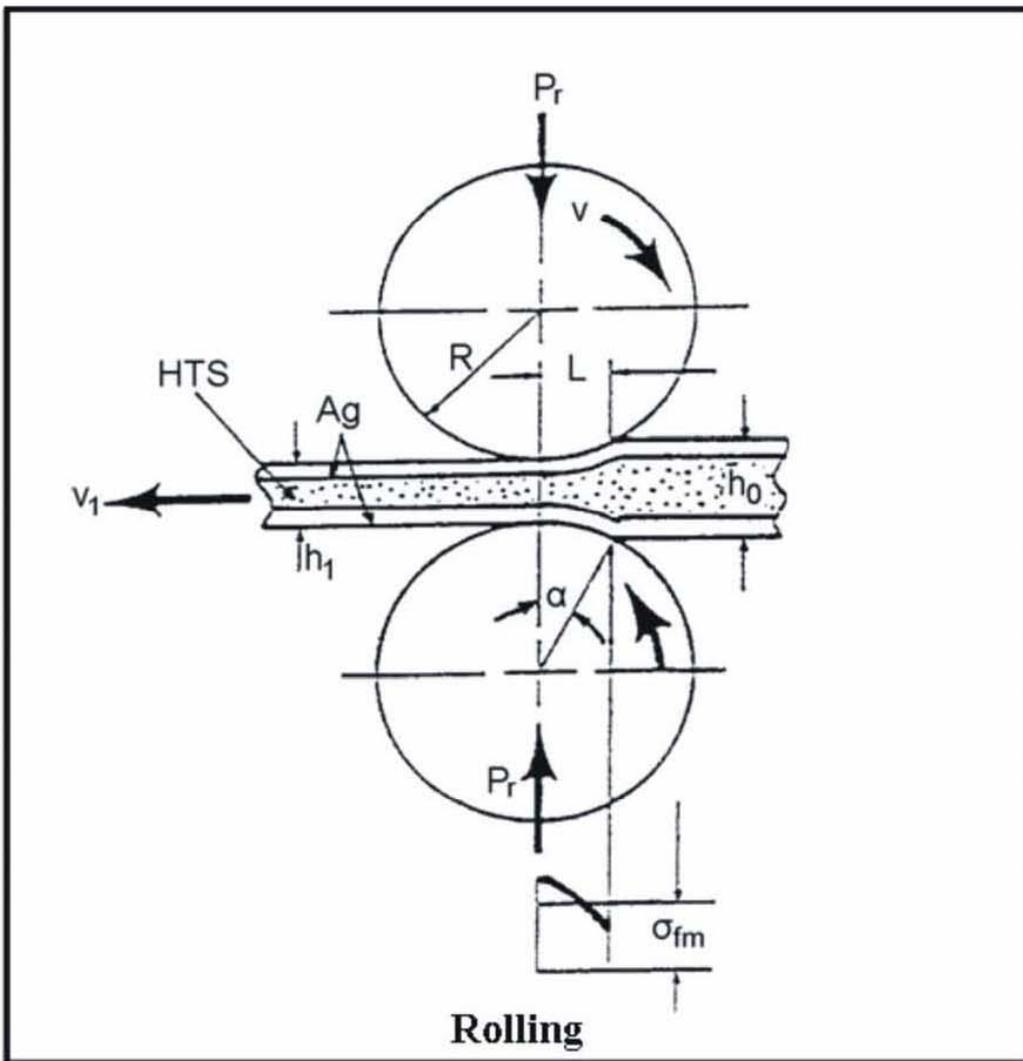
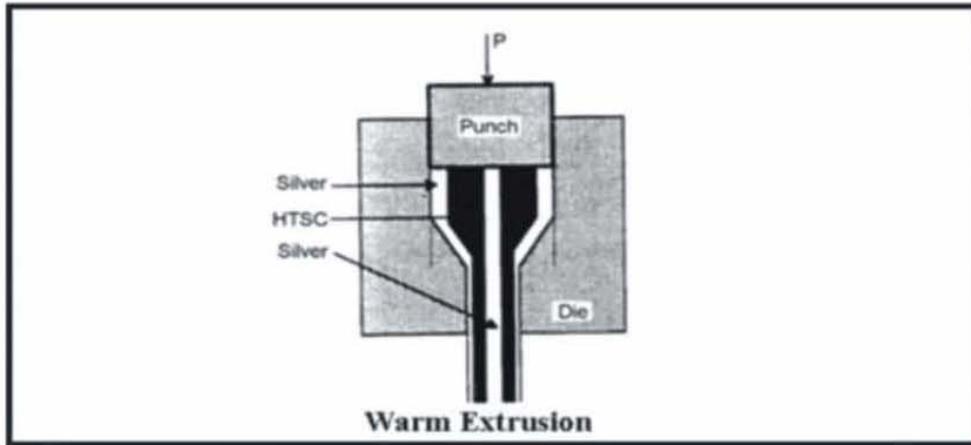
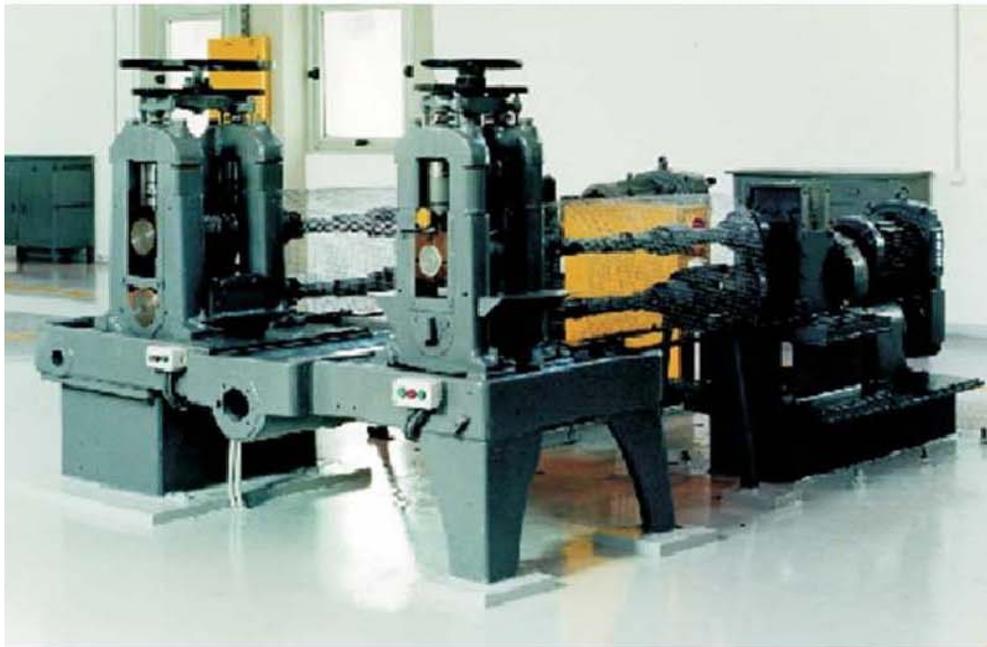


Fig. 8



A SMG vertical hydraulic press 1000 kN for forming, extrusion, sheet metal forming, powder processing and crash testing.

A drop-hammer with 6m drop-height and 100kg falling mass, providing strain-rates up to 100s⁻¹, for dynamic compression, forging, powder processing and crash testing.



Two 2-high rolling mills for flat and profile rolling operations

Fig. 9 Existing equipment of the LMT

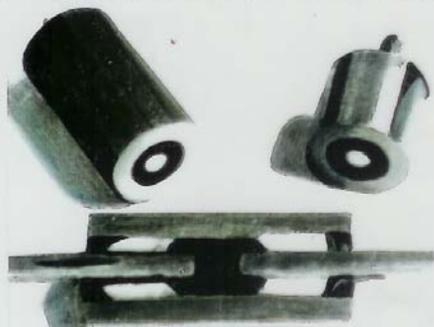
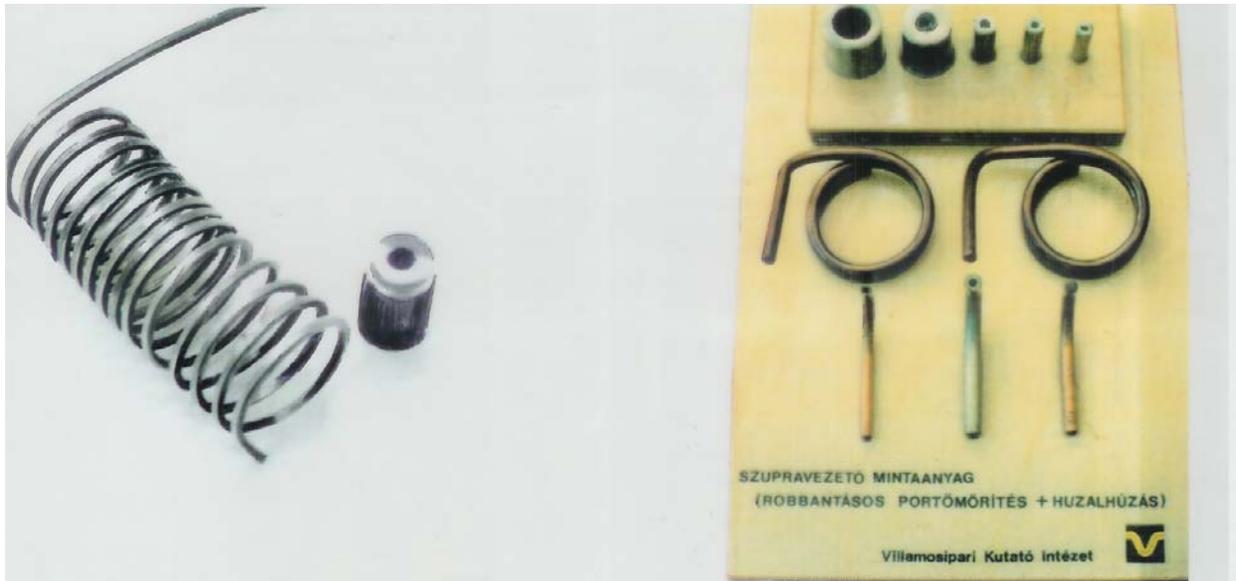


Fig.1. Metal sheathed HTSC samples

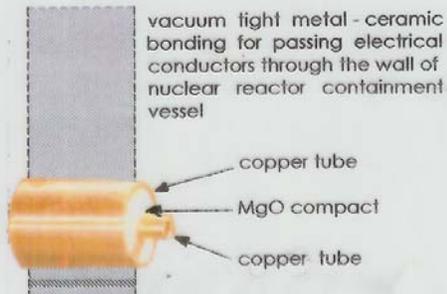


Fig.2. Electrical penetration assembly

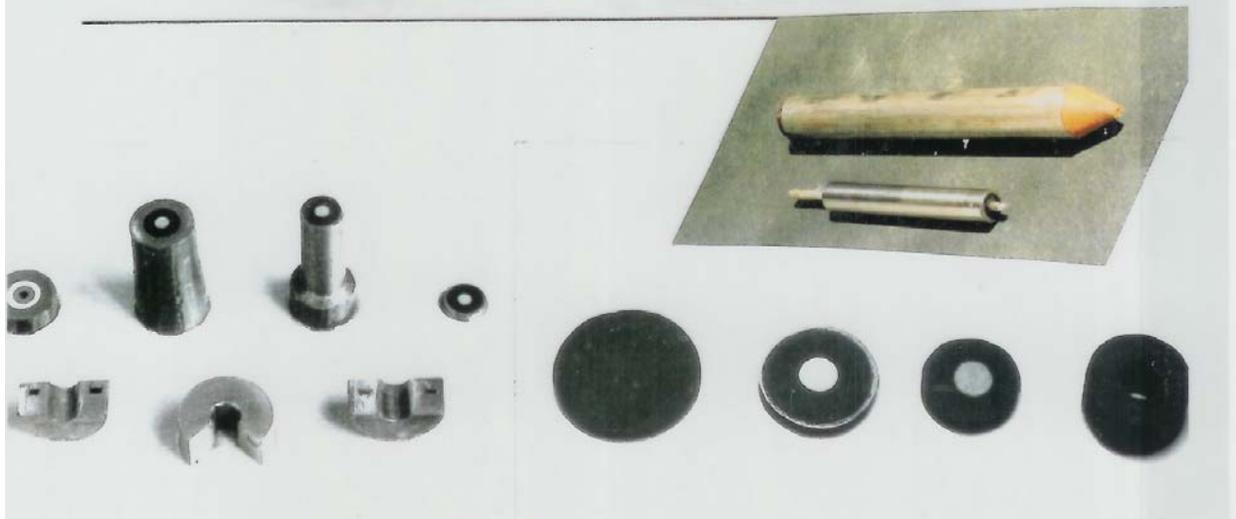


Fig. 10

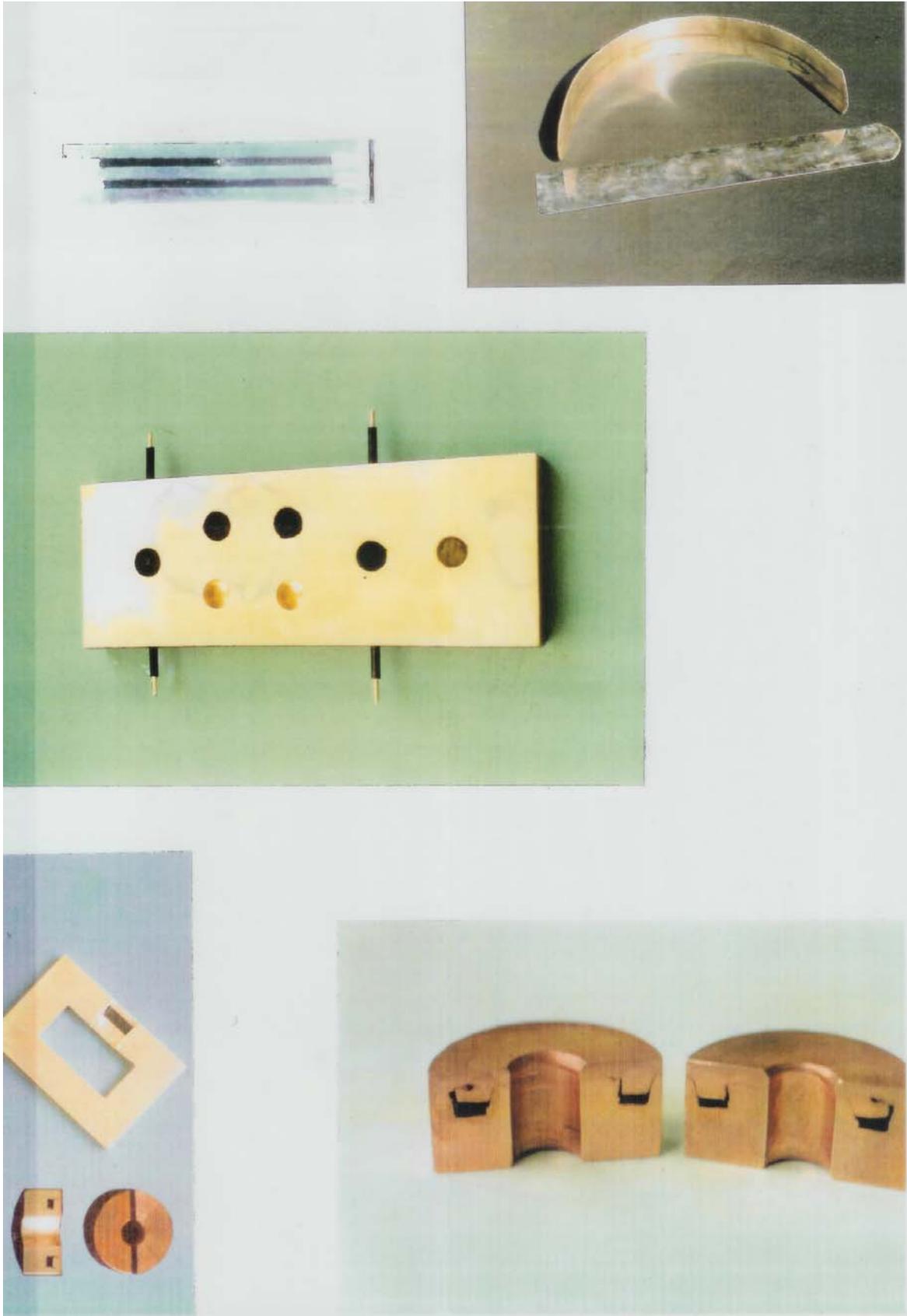


Fig. 11

Shock consolidation of powders is one-stage densification/bonding process that presents potential for the above mentioned special and difficult-to-consolidate materials. The shock waves, originated from explosive detonation and propagated through the porous media, can create high shock pressures and high temperatures that result in fracturing the original grains and in sintering, see

Fig. 12. The compacted solid contains a variety of primarily line defects that would provide flux pinning centers in Type II superconductors. Therefore, physical, see Fig. 13, analytical see Figs. 14,15, and numerical modelling, see Figs. 16-18, of the shock phenomena are of utmost importance.

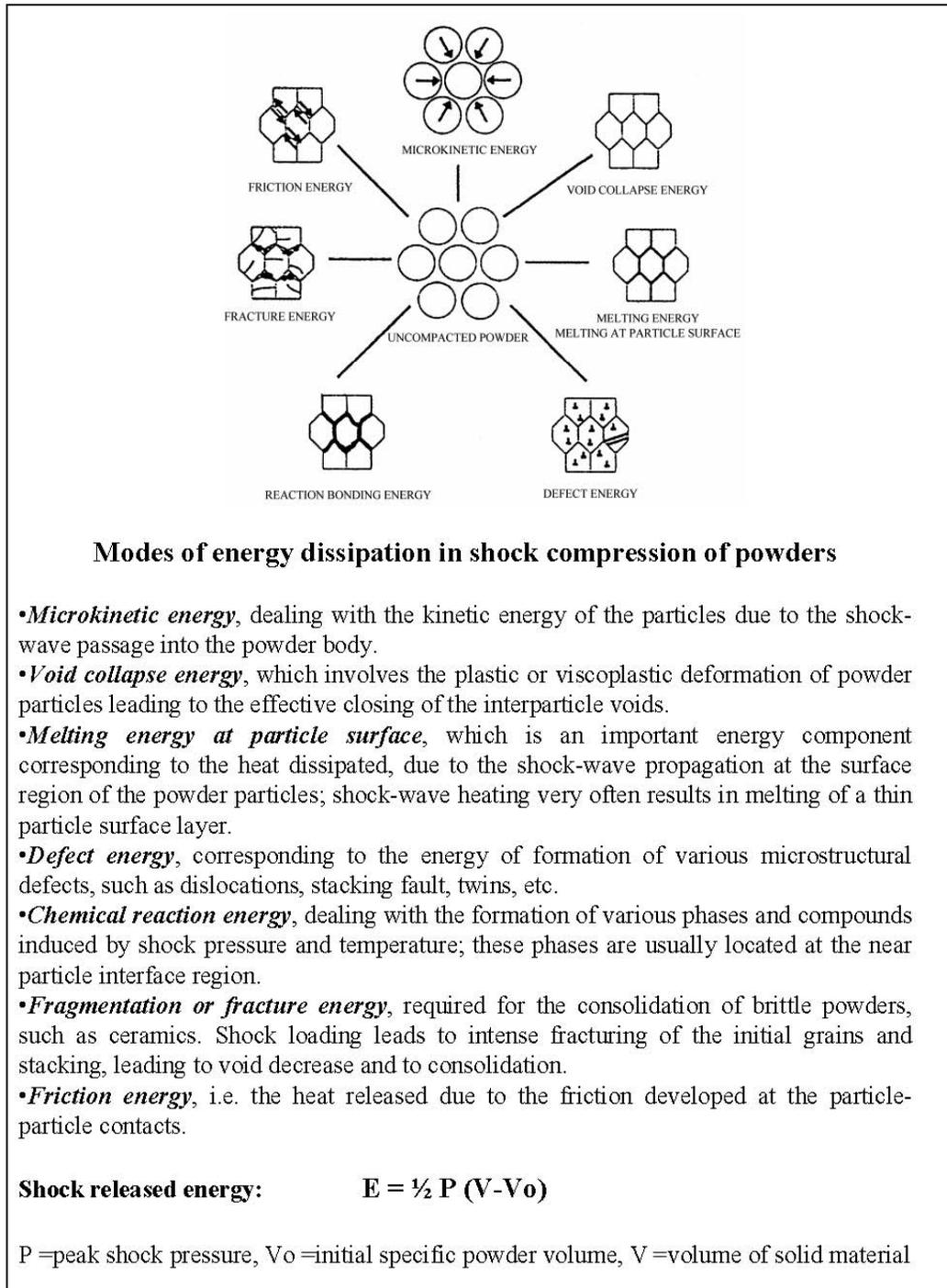


Fig. 12

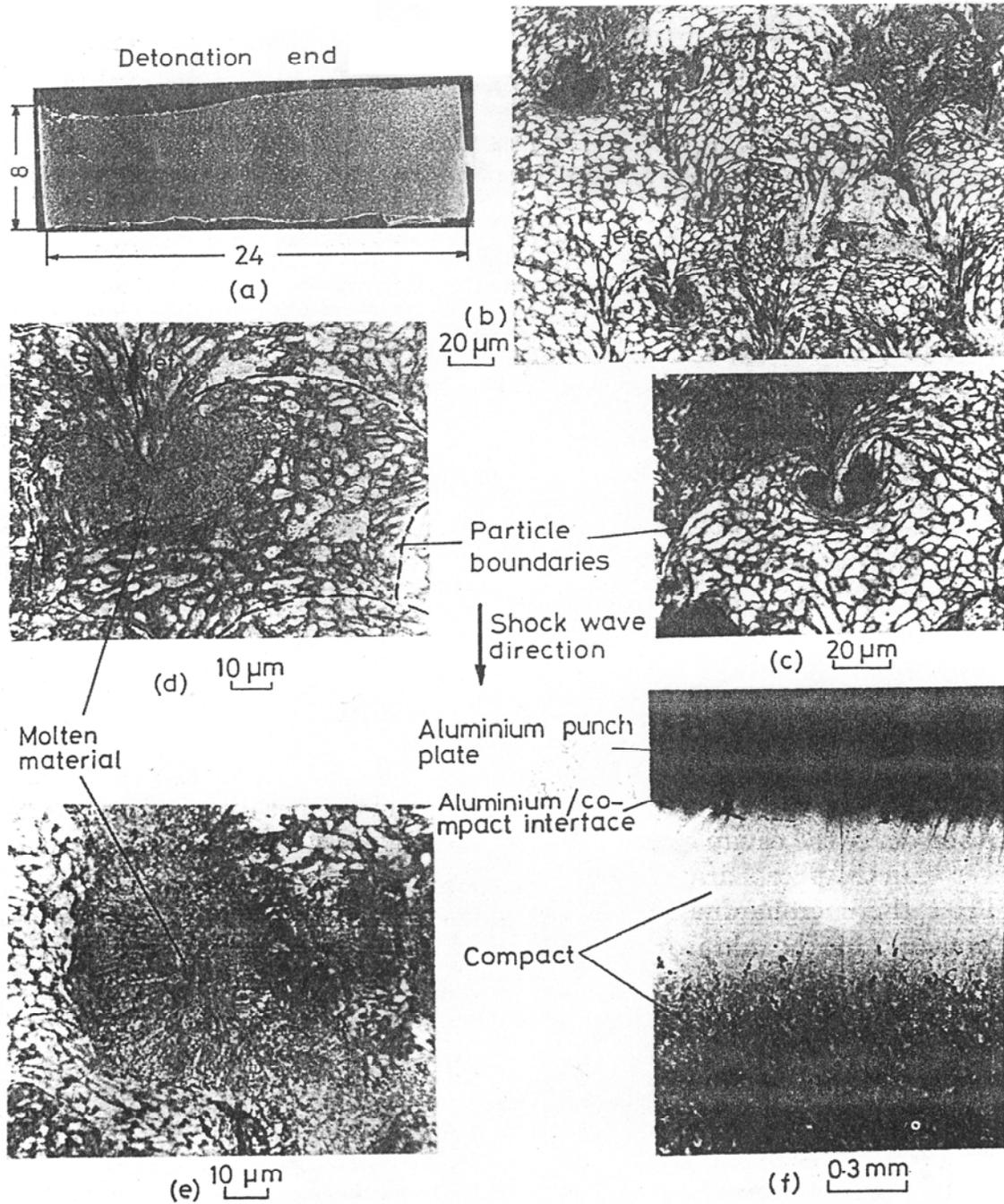


Fig. 3. (a) A cross-section of a copper powder compact sliced across a plane parallel to the compaction direction. Micrographs showing: (b) the particle shapes after compaction; (c) metal jet formation and plastic deformation of the grains due to jet impact; (d) a jet head of molten material entrapped in a cavity formed due to impact; (e) a channel of molten material with a column-like "as-cast" grain structure; (f) microstructural characteristics of the compact at the aluminium punch plate/powder interface.

Shock compaction mechanism

Based on the experimental observations outlined above, an attempt is made to explain the consolidation mechanism that brings the particle from its initial condition shown in Fig. 2 to its final consolidated state presented in Fig. 3(b).

A uniform particle arrangement of the powder-body consisting of spherical particles of diameter d is assumed at its initial stage, see the schematic representation in Fig. 4. It is considered that at a particular time, say $t=0$, the powder body is subjected simultaneously to:

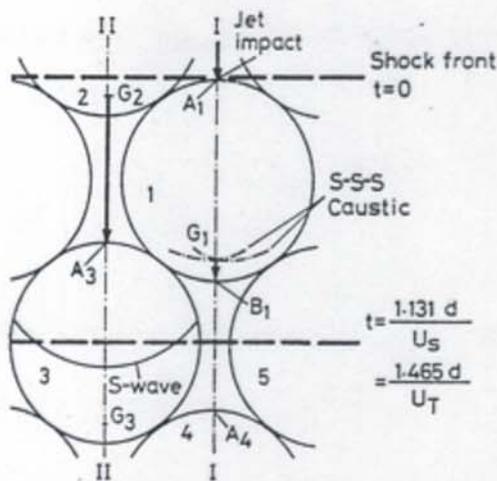
(i) The compaction shock wave travelling into the body with a speed U_s which can be calculated from the Hugoniot curve of the powder, as [12]

$$U_s = P/\rho_0 \cdot u_p$$

where P is the applied shock pressure, ρ_0 is the initial density of the powder body and u_p is the particle velocity¹.

(ii) A shear S-wave developed in the powder particles due to jet impact at a point on the particle surface, travelling inside the particle with speed $U_T = \sqrt{G/\rho}$ where G is the shear modulus and ρ is the density of the particle¹. Subsequent reflections of this wave at the spherical surface of the particle result in jet formation at point G, see Fig. 4 and Appendix.

(iii) Loading of the already formed jet moving between the interparticle voids with a speed U_j in the same direction as the shock¹.



A schematic representation of the initial particle arrangement subjected to impact loading according to the proposed consolidation mechanism.

¹For the copper powder and the explosive compaction conditions used in the present work: $U_s = 2150$ m/s; $U_T = 2780$ m/s; and $U_j = 3870$ m/s.

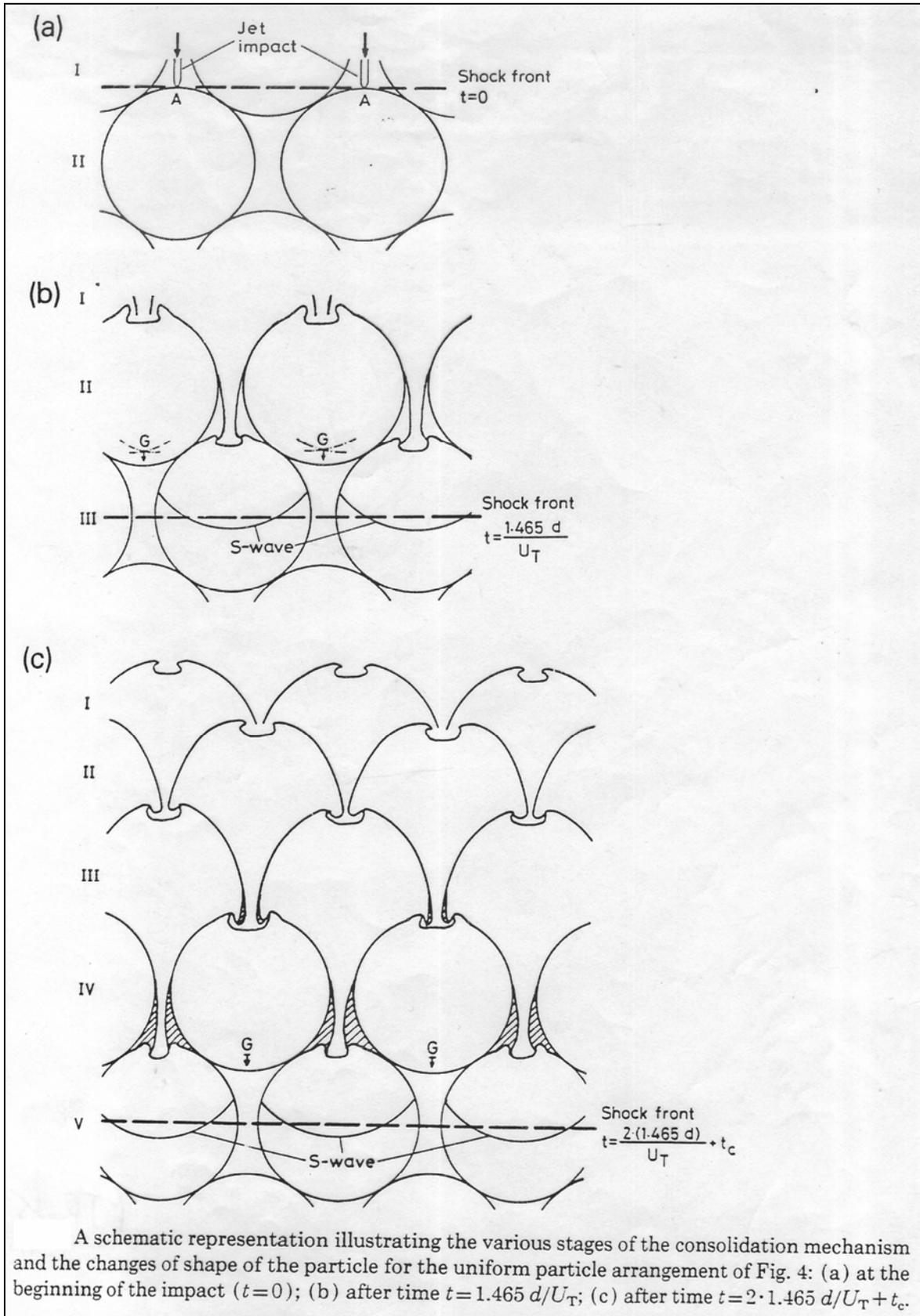


Fig. 15

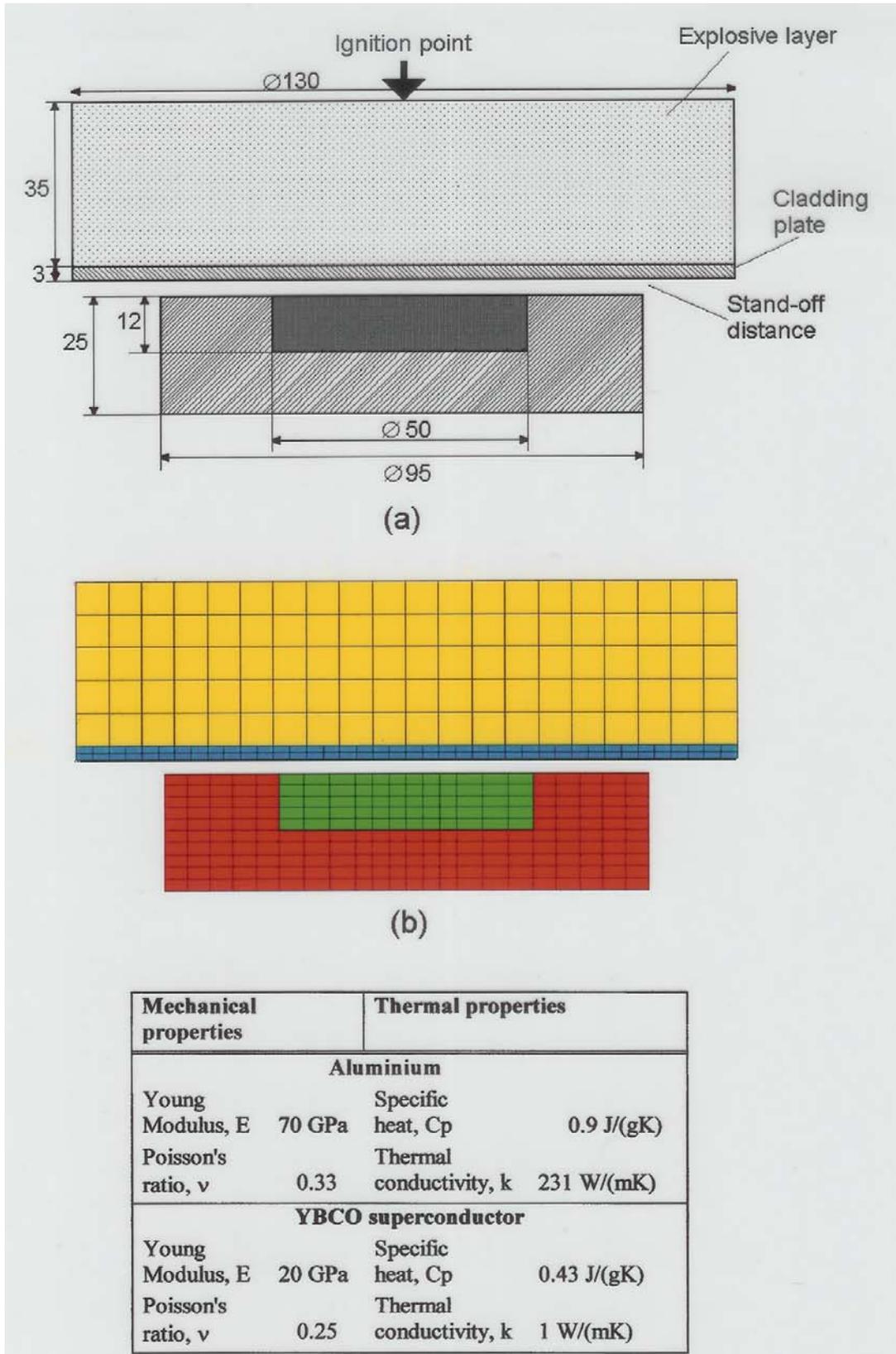


Fig. 16

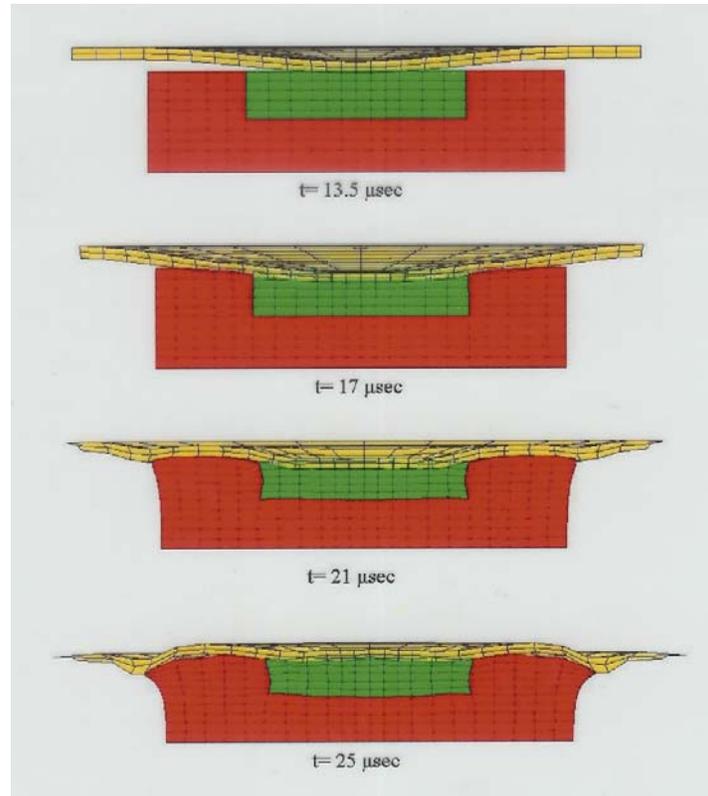


Fig. 17 Deformation of the metallic and superconducting disk at different time steps of the simulation of the cladding process.

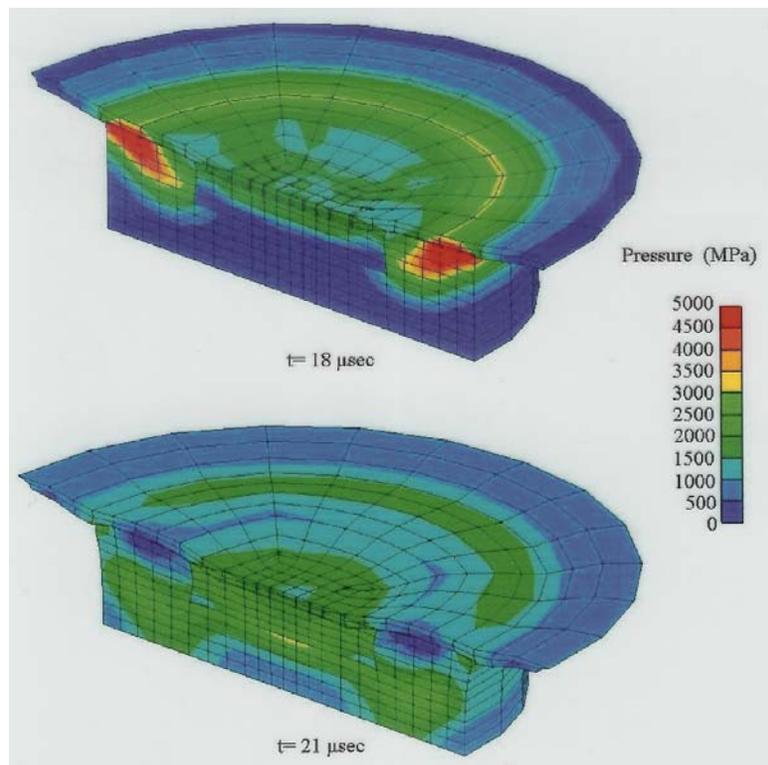


Fig. 18 Distribution of pressure inside the base and flyer metallic plates and the ceramic disc at two different time steps of the simulation

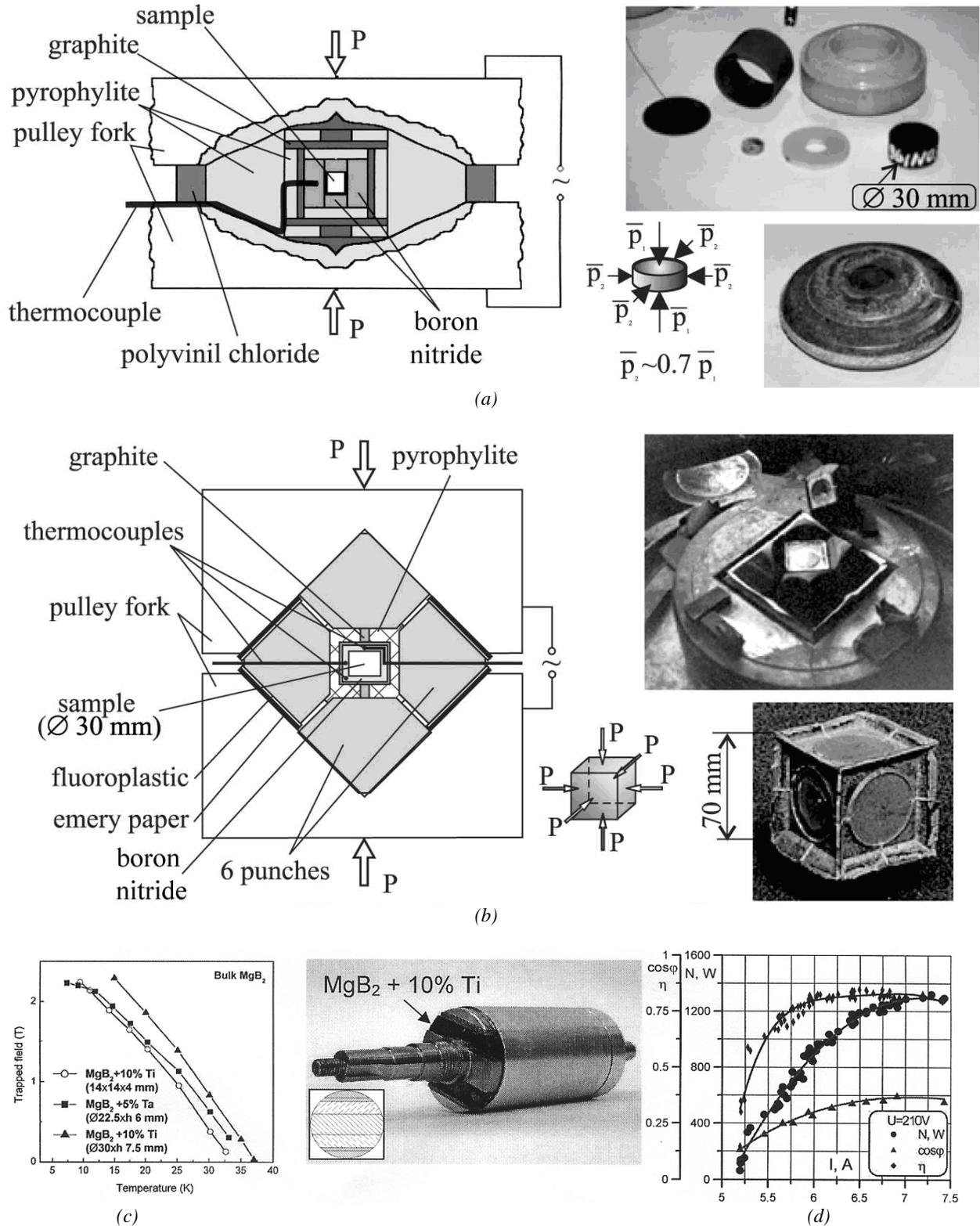


Fig. 20. High-pressure synthesized nanostructured MgB_2 . A schematic diagram and details of the (a) recessed-anvil and (b) cubic high-pressure cell; (c) The trapped field measured in the middle of the sample; (d) The zebra-type rotor of a superconducting motor with MgB_2 -Ti layers and performance characteristics of the motor at 15-20 K

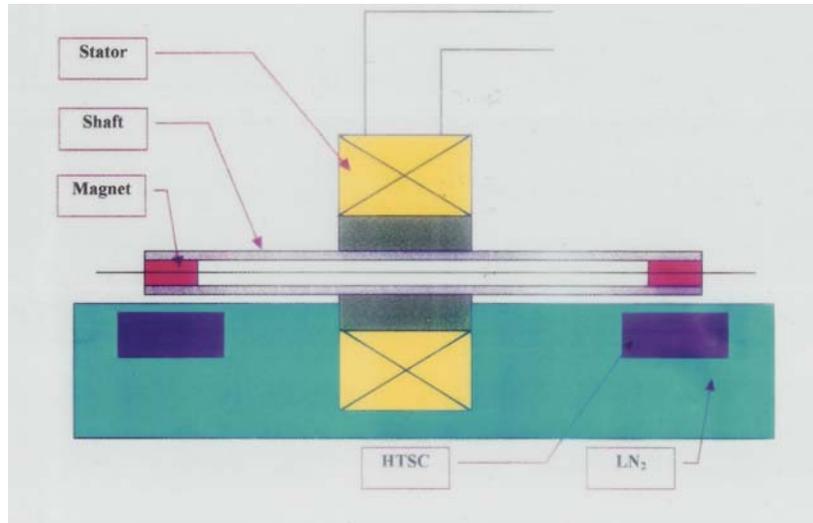


Fig. 21 Levitating Bearing

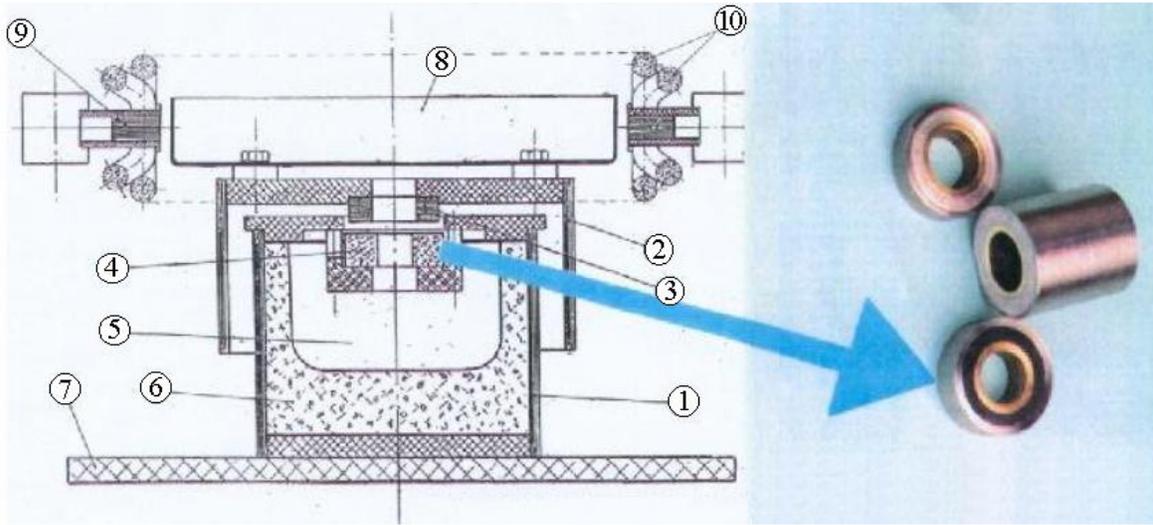


Fig. 22 Flywheel: 1-stator, 2-rotor, 3-permanent magnet, 4-superconducting magnet (HTS ring), 5-liquid nitrogen (LN₂), 6-vessel for LN₂, 7-base plate, 8-rotor cup, 9-stator core, 10-stator solenoid

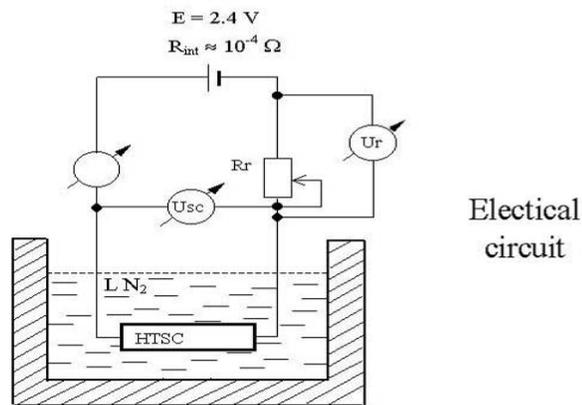
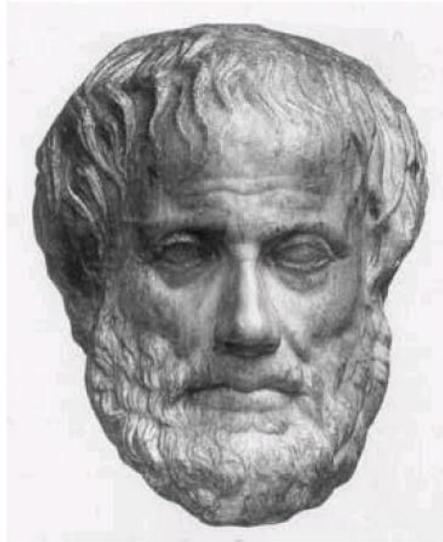


Fig. 23 Fault Current Limiter

4. Concluding Remarks

From all the above mentioned, it is evident that the benefits of such advanced materials, products and applications in many technological areas seem to be significant. The impact of these technologies in everyday's life is considered to be great, since it will make

communications, transportation, data storage, health treatment, energy conservation, environment and many other technological applications, faster, safer, cleaner and cheaper. *Aristotelis*, Fig. 24, recognized two millennia ago: "*Knowledge of the fact is different from knowledge of the reason for the fact*", which definitely leads to a great success, beneficial to all of us.



**“Knowledge of the fact is different from
knowledge of the reason for the fact”**

**ΑΡΙΣΤΟΤΕΛΗΣ
«Αναλυτικά Ύστερα»**

Fig. 24

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