The performance of sawing aids in hard rock working with diamond tools

The possibility of lowering the mechanical strength of crystalline materials by suitably acting on their environment was highlighted as early as the 1930s by the research of the Russian physicist Rehbinder, who produced evidence that the shear strength of crystals was considerably lowered by the presence on the crystal surfaces of suitable chemical compounds. Subsequent investigations, mostly carried out in the USA, confirmed Rehbinder's findings and gave them a sound theoretical interpretation that established the fundamentals of the new branch of technology called 'mechanochemistry'. The diamond tool machines employed in quarrying and working of hard dimension stone appeared as promising devices for the application of mechanochemistry owing to the fact that diamond tools demolish the stone by just applying shear stresses on their surfaces. Several tests, carried out in the second half of the last century in the authors' laboratory with a bench machine that simulated the action of diamond tools on granite and orthogneiss specimens yielded encouraging results and provided a wealth of information on the factors affecting mechanochemical effects produced on various hard stones by a variety of chemical compounds. This laboratory phase was followed, from 1996 onwards, by test runs on commercial machines in machine factories and quarries, and finally a full application of sawing aids was performed in quarries operated in Sardinia by various companies. The chemical compounds, of which the sawing aids consist, are added to the flushing fluids and the water solutions or dispersions thus obtained are highly diluted to the order of 10^{-3} M. These solutions or dispersions therefore should be not harmful for the environment. However, should the environmental regulations be particularly strict, recycling of flushing fluids according to a simple flowsheet is described for hard dimension stones working plants. The productivity improvements of diamond tool machines on hard dimension stones range from 40% to more than 100%, depending on various factors on which the paper provides adequate details. Paper by **G. Rossi, G. Loi, P. Trois** and **G. S.Andrissi**.

The influence of the physico-chemical environment on certain mechanical properties of crystalline solids was discovered in the 1930s by the Russian physico-chemist P. A. Rehbinder [1] and the solid state physics and physico-chemical fundamentals were studied by several researchers [2-21] who envisioned its major technological potential, naming this new branch of science and technology 'mechanochemistry'. Shear strength of crystalline solids is significantly reduced when certain chemical compounds are adsorbed on their surfaces and this effect has been exploited in oil well drilling in the Soviet Union [22]. In actual fact, drilling tools, especially diamond bits, demolish the stone chiefly by applying shear stresses thereto [23] (Fig 1).

The advent, in the late 1900s, of diamond impregnated tools – such as diamond discs and diamond wire that act on the rock in a manner that can be defined as 'abrasion' [24] – raised the interest of our Tool/Rock Interaction work Group (TRIG) that had been investigating the relationships between tools and rocks for several years. Research commenced in the 1970s culminated in the successful application of mechanochemistry to commercial dimension stone operations involving diamond disc and diamond wire machines. This paper describes TRIG's work and the technological progress achieved.

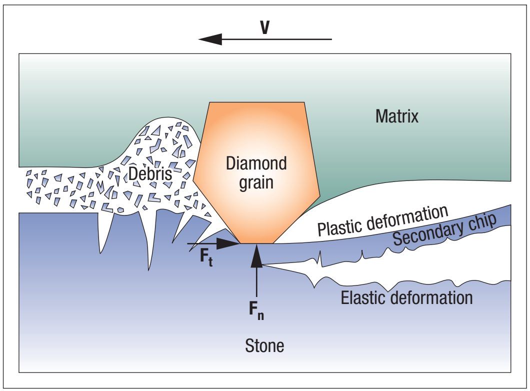
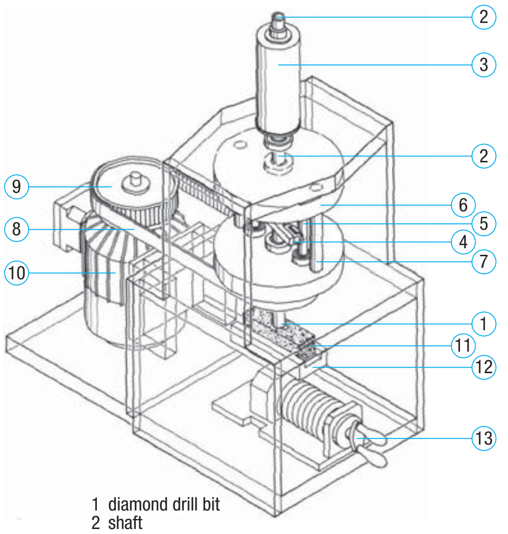


Fig 1 Tool/rock interaction:
V = linear velocity of diamond wire;
F_n = normal force per grain;
F_t = tangential force per grain (after [23])

Early laboratory test work

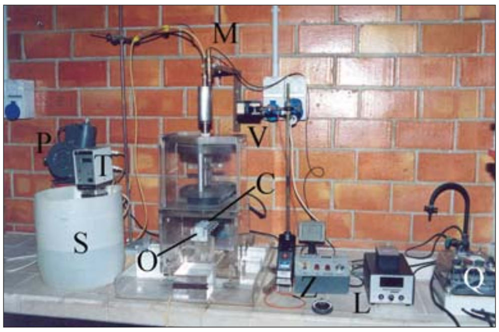
For the experimental work the TRIG designed and developed a laboratory bench machine [25], shown in the isometric view of Fig 2, and in the picture of Fig 3.

It consists of an instrumented bench drill with a diamond-coring bit – with inner diameter of 10 mm and outer diameter of 18 mm – that drills circular grooves on rock specimens of suitable geometry, usually rectangular prisms with 20 x 20 x 120 mm edges. This low-cost set up provides a large amount of statistical information on rock/tool interaction for various rock types using a variety of chemical additives dissolved or suspended in the flushing fluid. The thrust applied to the bit, its rotating speed and the duration of each test are predetermined as well as the flushing fluid flow rate, adjusted by means of a peristaltic pump.



1 diamond drill bit
2 shaft
3 ballast (weight for producing normal force)
4 arm keyed to shaft 2
5 rods which push the arm 4
6 frame idle on shaft 2, set in rotation by belt 8
7 spacer rod of frame
9 electric motor pulley
10 electric motor
11 rock specimen
12 specimen holder
13 specimen position selector

Fig 2 Isometric sketch of bench testing machine



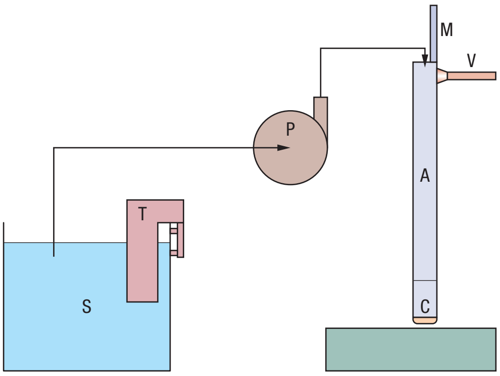
P peristaltic pump for flushing fluid
S thermostated flushing fluid bath
T thermostat
M shaft rate of advance sensor
V sensor of optical tachometer
C diamond drill bit
O specimen holder
Z electronic control system
L shaft rate of advance monitor

Fig 3 Overall view of experimental setup

The temperature of the flushing medium is thermostatically controlled. Two sensors, one for monitoring the rotating speed and the other for measuring the penetration rate, i.e. the depth of the groove produced per unit time, complete the device shown in the photograph of Fig 3 and in the schematic sketch of Fig 4. Some specimens are shown in photograph of Fig 5. Laboratory procedures were subsequently developed by another research group [26], for other objectives, but the above described procedure was considered the most appropriate for the mechanochemical investigations also because it allowed to regulate and monitor the flushing fluid flowrate.

Several tests were carried out with this bench test equipment on hard minerals (e.g. quartz) and on hard igneous rocks (granite, andesite and basalt) using a variety of chemical additives (single or combined).

The results of these tests have been published in several papers [26-33] and produced evidence that the shear strength of quartz and igneous rocks could be considerably reduced using a flushing fluid containing adequate concentrations of certain chemical compounds. However, while the tests were quite reproducible when an inorganic salt was used as chemical compound, strong variability was almost always observed when an organic compound, e.g. a primary amine, was used as additive. A major factor affecting this variability was found to be the temperature. A series of tests was therefore carried out paying particular attention to flushing fluid temperature and considering the actual nature of the aqueous mixture of those chemical compounds. This investigation showed [34] that often the mixtures are actually suspensions of micelles of the chemical compounds used and for primary amines mixtures the most suitable temperature was found to be around 40 °C.



S thermostated bath
T thermostat
P peristaltic pump for flushing fluid
M shaft rate of advance sensor
V sensor of optical tachometer
A shaft
C diamond drill bit

Fig 4 Schematic of experimental setup

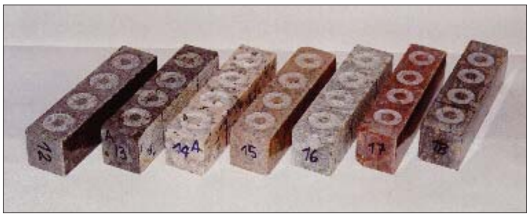


Fig 5 Array of specimens: grooves cut by diamond bit are clearly visible

Field tests and pilot tests

The experimental results were so encouraging to warrant conducting field tests. The first step was the choice of rock and machine type. By the time the programme had been prepared diamond wire was being widely used for granite quarrying and the machines employed were similar to those successfully used for the primary sawing of marble and other relatively soft rocks like travertine [35] and shown in the layout of Fig 6.

Block cutting was usually carried out in the processing plant using a gangsaw. The only diamond wire block cutter operating successfully was at a plant located in Canton Ticino, Switzerland, and was used for sawing blocks of orthogneiss into slabs. The machine depicted in Fig 6 had been replaced, in some Sardinian granite quarries, by the much more effective CMS (Costruzioni Meccaniche Sini) machine [Figs 7 and 8], patented and manufactured by a factory located in Sardinia's granite quarry area. This machine proved especially suitable for testing the sawing aids, as being fully hydraulic, the flushing fluid could be heated at no additional cost. It was also easier to regulate and monitor the operating variables (e.g.wire tension, speed and angle of entry into the bench). The Italian company Breton granted the permission to conduct tests on a block cutter prototype, they had patented and manufactured, equipped with a diamond impregnated segments chain.

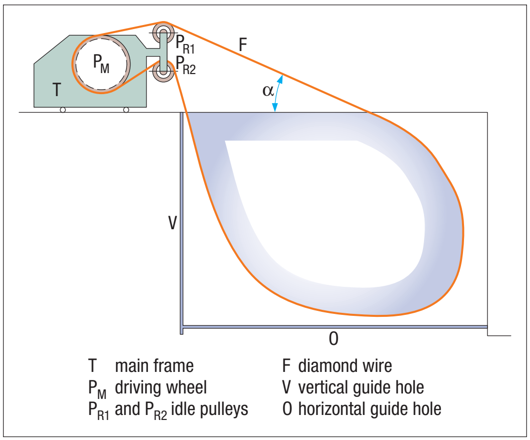


Fig 6 Scheme of conventional closed loop diamond wire sawing machine for primary quarrying

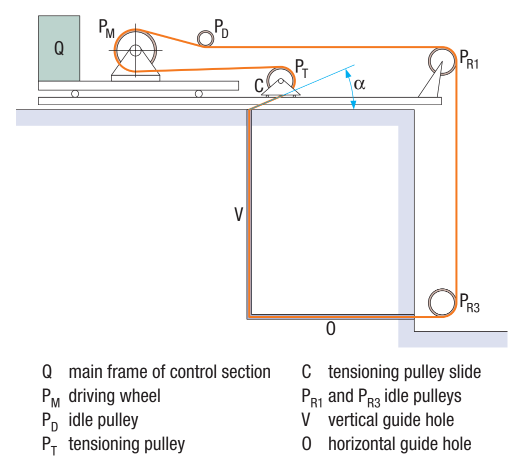


Fig 7 Scheme of innovative all hydraulic CMS diamond wire sawing all purpose machine used for testing sawing aids in primary quarrying

Therefore, the testing programme was developed for the CMS machine for Sardinian granite and for the block cutting machine for Swiss orthogneiss; whereas the block cutting prototype was operated on Sardinian granite.

Testing with the CMS machine was carried out in four Sardinian granite quarries (Fig 9) and was financially supported by the C21, an agency created by the Sardinian Regional Government for providing advice and support to local innovative enterprises.

The pilot testing carried out on orthogneiss with the diamond wire machine and on granite with the prototype were funded partly by the Italian Ministry for University and Research and partly by the companies operating the machines.

The addition of mixtures of fatty amines to the flushing fluid was also found to improve sawing productivity, though to different extents, as shown in Fig 10 [36-38].

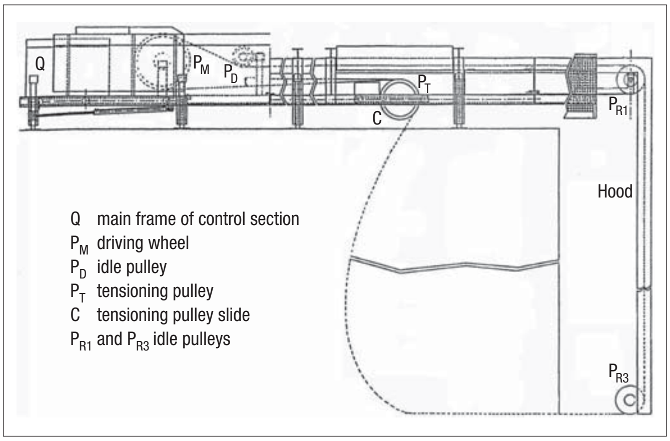


Fig 8 Overall drawing of innovative all hydraulic CMS machine shown by scheme of Fig 7

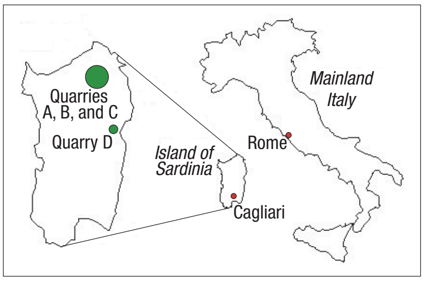


Fig 9 Map showing the Island of Sardinia and the areas of the quarries of the sawing aids pilot project

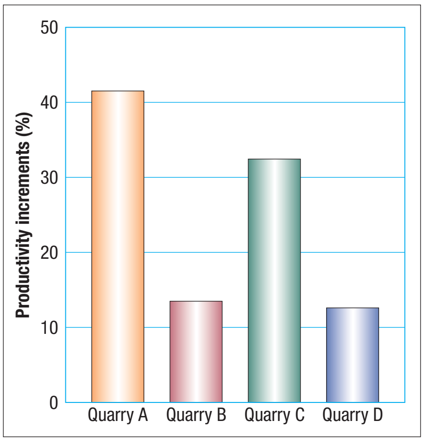


Fig 10 Productivity increments achieved with sawing aids in the four quarries of the pilot project

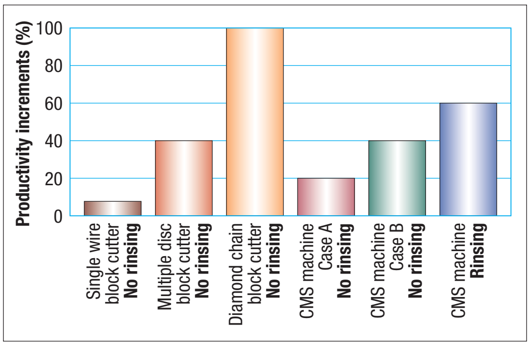


Fig 11 Productivity increments achieved with sawing aids by different machines and modes of operation

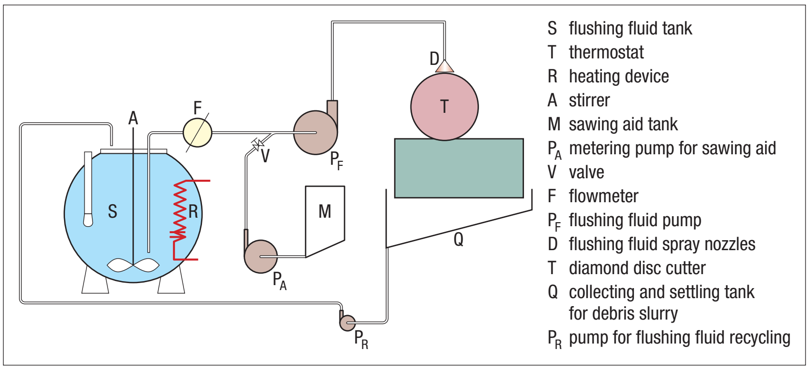


Fig 12 Flowsheet of sawing aid addition to flushing fluid for indoor block cutters

Further investigations elucidated these differences that could not be explained merely by the lack of rock homogeneity or by small differences from one rock to another. The findings demonstrated that the type of machine and the sawing mode of the diamond tools had a pronounced effect on sawing aid performance, diamond disc and diamond impregnated segments chain cutters outperforming the diamond wire saw units, disc or diamond segments chain cutters, as Fig 10 [39-41] shows.

The difference in performance of the diamond wire machines (irrespective of whether they are mounted in quarry machines or block cutters) was found to be caused by rock debris coating the wire while no debris adheres to the diamond tools of the disc machines [41]. This coating seriously affects the ability of the wire to eliminate the cuttings, because it increases the wire diameter, thereby impairing sawing efficiency [42]. This drawback was remedied simply by alternating the sawing aid water mixture with plain water: the latter rinses the wire flushing the debris coating away, thus restoring the full transport capacity of the diamond wire. Fig 11 clearly shows that the benefit of rinsing, cutting productivity with the diamond wire increasing by more than 20%.

For block cutters that operate indoors, the simple flowsheet shown in Fig 12 can be adopted. Last, but not least important, the potential environmental impact of sawing aids should be mentioned. Although the flushing fluids contain very low concentrations of sawing aids, in the order of 10^{-3} moles dm^{-3}, most of these substances are not adsorbed onto the rock or debris and are removed with the latter. These compounds may have, or may be thought to have by local environmental protection agencies, a detrimental impact on aquatic life.

Disposal of the cuttings suspension in suitable settling ponds, where the chemicals can easily be biodegraded [43], may be the most convenient answer to this problem.

The flowsheet of Fig 12, suitably integrated with a flushing fluid recycling circuit, represents an optimum solution to the problem, insofar as indoor recycling may reduce sawing aids costs as well as avoiding any discharge into natural water bodies.

Finally, it can be anticipated based on the preliminary results of field investigations still under way and of some empirical observations, that the sawing aids also appear to have a beneficial effect on diamond tool wear which is significantly reduced. This confirms earlier findings reported by other researchers [44] concerning additives in hard rock drilling. More details on this economically important issue will hopefully be provided in future reports.

Conclusions

The benefits of sawing aids in hard rock cutting machines can be seriously undermined by their improper use. Accurate monitoring of operation mode and of the influence of the most important parameters (flushing fluid composition, flow rate and temperature, cleanliness of the diamond tools, relative rock/tool velocity) is therefore very important and deserves due attention. Experience gained during plant operation can achieve further savings in sawing aid costs.

The authors believe it appropriate to conclude by quoting the concluding remarks of a paper published about forty years ago by two forerunners in this field [45]: "We believe that anything that helps to reduce costs in diamond drilling or sawing will benefit not only the users concerned but also the diamond industry as a whole by making diamond tools more economical and efficient and therefore capable of far wider applications." ◆

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