

BEHAVIOR OF POLYCRYSTALLINE DIAMOND COMPACT CUTTERS WHILE DRILLING IN BOTTOMHOLE CONDITIONS - FIELD APPLICATIONS

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ABSTRACT

This paper describes research carried out during several years on polycrystalline diamond compact cutters and includes two main parts.

1. Laboratory Study on the Behaviour of Polycrystalline Diamond Compact Cutters

C.F.P. decided to develop a drilling simulator especially designed to show the elastoplastic destructive rock behavior under bottom-hole conditions.

Major characteristics of this simulator are as follows:

- Rotating speed: up to 300 rpm
- Test pressure: up to 600 bars
- Visualization of cutter action with a high-speed camera: (up to 10,000 pictures per second)
- Measurement of cutter temperature while drilling
- Measurements of the bit weight, torque, rate of penetration, and bottomhole pressure.

The results allowed the definition of the different parameters that improve the rate of penetration:

- Rake angle
- Clearance angle
- Side clearance angle
- Cutter configuration

2. Field Applications

Following the laboratory results, new drill bits were designed and field tested.

From the numerous tests which were performed in the field, it was then possible to compare standard bits with new bits in the same drilling conditions. Major emphasis has been given to a study of turbodrilling and the bit performance at high rotating speeds.

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Diamond drilling bits have been used a long time in petroleum drilling, but until recently their use has remained limited. This is because of their very high purchase cost, and because of the need for a high speed of rotation, which is not always easy to achieve in rotary drilling except at the cost of various stresses, which all affect equipment wear.

Hence it is in hard and semi-hard terrain that diamond bits find their calling. Jointly with a manufacturer, Total Compagnie Française des Pétroles has developed LX type bits featuring diamond compound blades, designed to guarantee both form of cut and good wear resistance.

Increasing rig costs and the installation of large pumping facilities have made the intensive use of a high speed rotary turbine unit combined with diamond bits of the LX or large stone more competitive in soft terrain.

In 1975, General Electric began rotary drilling tests in the USA with a new material called Stratapax. At the outset, it had the disadvantage of high cost in comparison with diamond. These tests proved negative, and the future of this material appeared to be jeopardized among manufacturers and users.

Despite these failures, Total Compagnie Française des Pétroles, with its long experience in this field, gained studies carried out with LX type blades, showed an interest in this new material.

To avoid identical results and costly drillsite trials, we conducted a series of tests in our laboratories to understand the rock destruction mechanism with Stratapax. An LX type bit combined with Stratapax was prepared.

The first test was performed in early 1976 on our Total ABK drillsites in Abu Dhabi. This represented the first time ever that a Stratapax bit combined with a bladed turbine was lowered into a well. The results were excellent, but was not competitive cost-wise.

The third test in the same formations was performed in March 1977 (footage 2168'; R.O.P. 40 ft/h). This test constituted a record and an economically competitive performance, and gave this equipment a second wind.

Following this the Stratapax bit was taken up in North Sea area at the end of 1977 and only moderate success was achieved up to March 1979. Thereafter excellent results were recorded.

It can now be said that the Stratapax bit has found its place in the petroleum drilling industry. Hopes materialized of making diamond bits competitive in extremely soft terrain in comparaison with the three-cone bit. Since then, we have drilled 1,068,602 feet with 12 1/4 inch diameter Stratapax.

The following pages discuss this experiment and the laboratory and drillsite tests.

LABORATORY INVESTIGATIONS

STUDY OF THE BEHAVIOUR OF POLYCRYSTALLINE DIAMOND BLADES

Equipment -- C.F.P. has developed a cell designed to examine the work of a blade bit or cutting element alone in downhole conditions.

The operating characteristics were as follows :

service pressure : 8 500 psi
speed of rotation : up to 300 t/mn,
weight on bit : up to 10 tons.

Measurements can be taken at constant rate of penetration, or at constant weight on bit.

It is possible to measure and to record the speed of rotation, weight on bit, torque generated, rate of penetration, and temperature rise of the blade or bit during drilling.

The cell is equipped with windows for visual observation of the different mechanism involved during drilling. This is achieved by a high-speed camera with a shutter speed exceeding 10,000 images/second.

Test conditions -- The tests were performed at confining pressures of 40 bars, 200 bars and 400 bars.

The speed of rotation was set at 100 r/min.

Each test was performed under constant vertical force.

In all cases, the giration diameter was set at 160 cm.

The rock samples consisted of Frangey limestone or Soignies limestone.

Visual observation was carried out at 3 000 images/second.

Rocks used

Soignies limestone (see figure 1)

Blades employed

We investigated two different Stratapax profiles :

'cylindrical' Stratapax (figure 2)

'cubic' Stratapax (figure 3)

In both cases, we analized the effect of two angles making up the configuration of a blade.

Rake angle (figure 4)

Clearance angle (figure 5)

Results and analysis -- Visual observation of the work of a blade during drilling using a high-speed camera served to reveal at least two types of rocks destruction :

If the weight applied is low, or if the blade edge is of poor quality, the rock is drilled by abrasion.

In case of "normal" blade work, and for rocks such as the Frangey and Soignies limestones, several state changes occur in the rock structure. Destruction is preceded by an elastic phase, followed by a plastic phase. Fracture occurs suddenly,

and is characterized by the decoherence of the rock grains and crystals located in the zone disturbed by the passage of the bit.

EFFECT OF RAKE ANGLE γ ON DRILLING EFFICIENCY

Various rake angles were investigated during the tests :

$$\gamma = +10^\circ \Rightarrow \gamma = -30^\circ$$

Positive angles - The first tests were performed on blades of which the clearance (15°) was cut just downstream of the Stratapax diamond portion (figure 6), yielding very poor results. This is explained by the existence of a rake angle which is actually 70 to 80° on the edge, giving rise to balling up at the edge. (figure 6) Blades cut with a 15° rake on the edge proved effective but very brittle.

Negative angles - (figure 7)

$$(\gamma = 0 \Rightarrow \gamma = -30^\circ)$$

The clearance was 15° in each case and was cut from the lead edge.

No significant difference was detected, except for a certain brittleness for the blades $\gamma = 0$. The $\gamma = -30^\circ$ Stratapax Blade was slightly less efficient.

Temperature rise - In all cases, the temperature rise was stabilized at 220°C for a weight on bit of 250 kgf.

Effect of edge quality -- In cases in which F_V is around 350 kgf (optimum weight for penetration without destruction of the Stratapax), the rate of penetration was about $1/10$ mm per turn. This means that the blade penetrates into the rock over the same distance, and that the lead angles must be considered in this order of magnitude. It is obvious that a blade with such a perfect lead edge is very difficult to obtain, and if so, the state of this edge is rapidly degraded until it reaches its equilibrium form (rounded edge).

Recent advances achieved in cutting Stratapax bits enabled us to perform tests with identical angles, but in which the state of the edge was not the same. This

applies to tests performed for $\gamma = -5^\circ, -10^\circ, -20^\circ$ and -25° . (See curves and photographs taken by the scanning electron microscope). (figure 8 - photos 2-3)

Importance of blade configuration (cubic and round)-

The following was observed for angles $\gamma = 0 \rightarrow \gamma = -30^\circ$ with clearances of 15
lower temperature rise in "cubic" blades,
slightly higher torque for cylindrical blades,
identical rate of penetration for both types of blade (figure 4), curve

$\gamma = -20^\circ$, cubic and round blade, $F_V = f(E_S)$.

Effect of clearance angle -- Four clearance angles were investigated :

$\beta = 0^\circ, 5^\circ, 10^\circ, 15^\circ$.

The rake angle γ was 0° in each case.

Clearance angle $\beta = 0^\circ$ a low rate of penetration was observed, the torque was relatively low, and the temperature rose very quickly to 600°C . (figure 6b).

Clearance angle $\beta = 5^\circ$ - Temperature rise 300°C , penetration and efficiency 20% of that of a blade with a larger angle.

Clearance angle $\beta = 10^\circ$ or more - Temperature rise about 220°C , normal torque, optimum penetration. (cubic configuration)

DRILLSITE RESULTS

The performance figures given in the table below were obtained on different drillsites where Total Compagnie Française des Pétroles also uses Stratapax bits.

The results obtained are competitive from the cost standpoint with three-cone bits in 75% of the cases analyzed. In this table, we have included all the prototype bits. Hence it is certain that if the bit development tests are eliminated, this advantage rises to about 90% of the cases.

(See table I - "Diameter 12 1/4 inch").

This tests were all performed using a T311 Neyrfor 9 1/2 inch turbine.

These experience allows us to conclude with several recommendations on the usage of Stratapax bits : this type of tool is very weight-sensitive, it is therefore necessary to drill with a low weight-on-bit (this phenomenon has been verified in our laboratories).

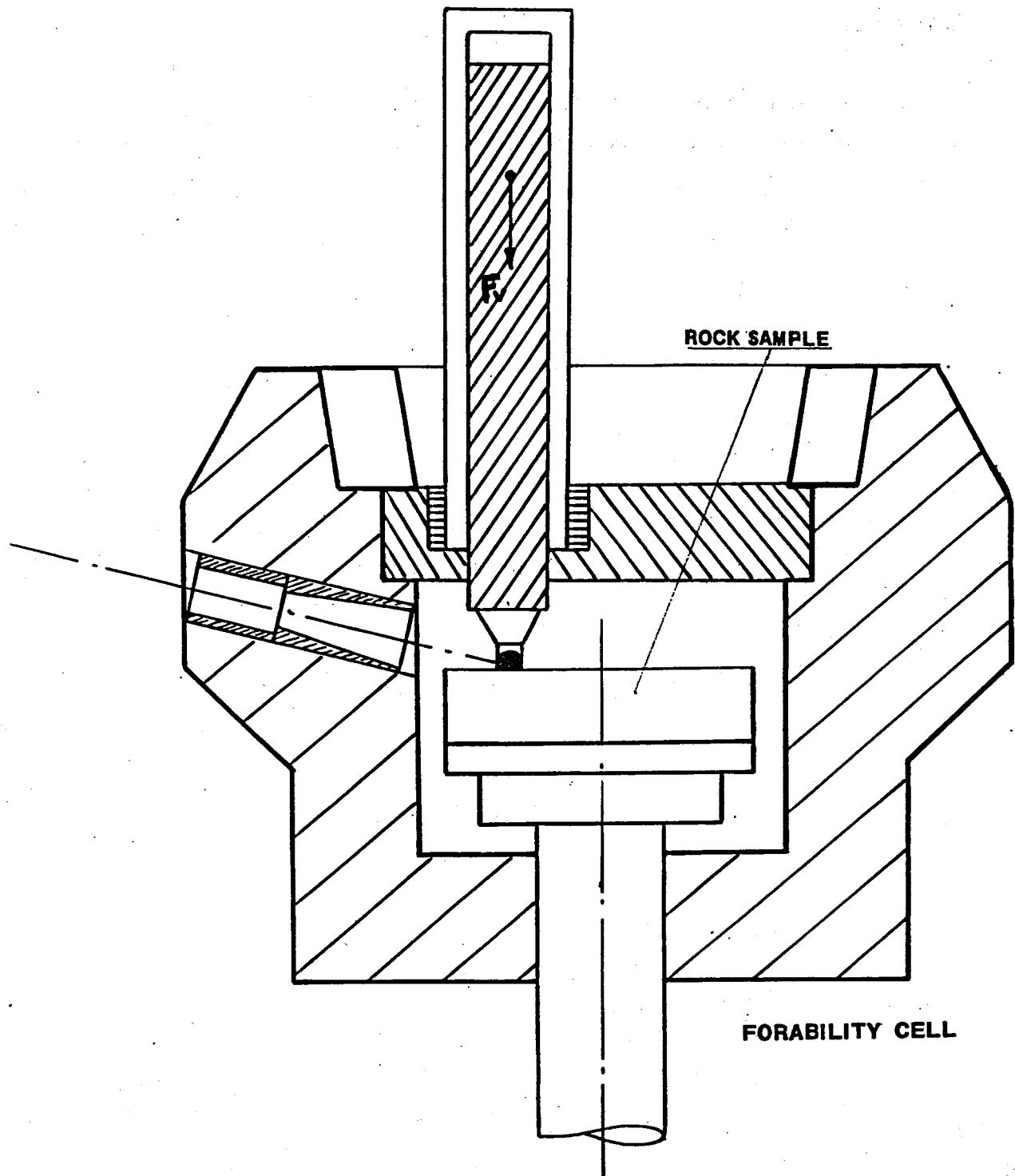
For this reason Stratapax bits are applicable to drilling soft to very soft formations.

In the case of medium-soft formations alternated with hard layers it is necessary to use a diamond + Stratapax combination tool.

TABLE I

Diameter 12 1/4 inch

number of bits	distance drilled	rate of penetration	average distance drilled by bit	average life of bit
141	1,068,602 ft	20 ft/h	722 ft	36.1 h



CALCAIRE DE SOIGNIES

Courbe intrinsèque

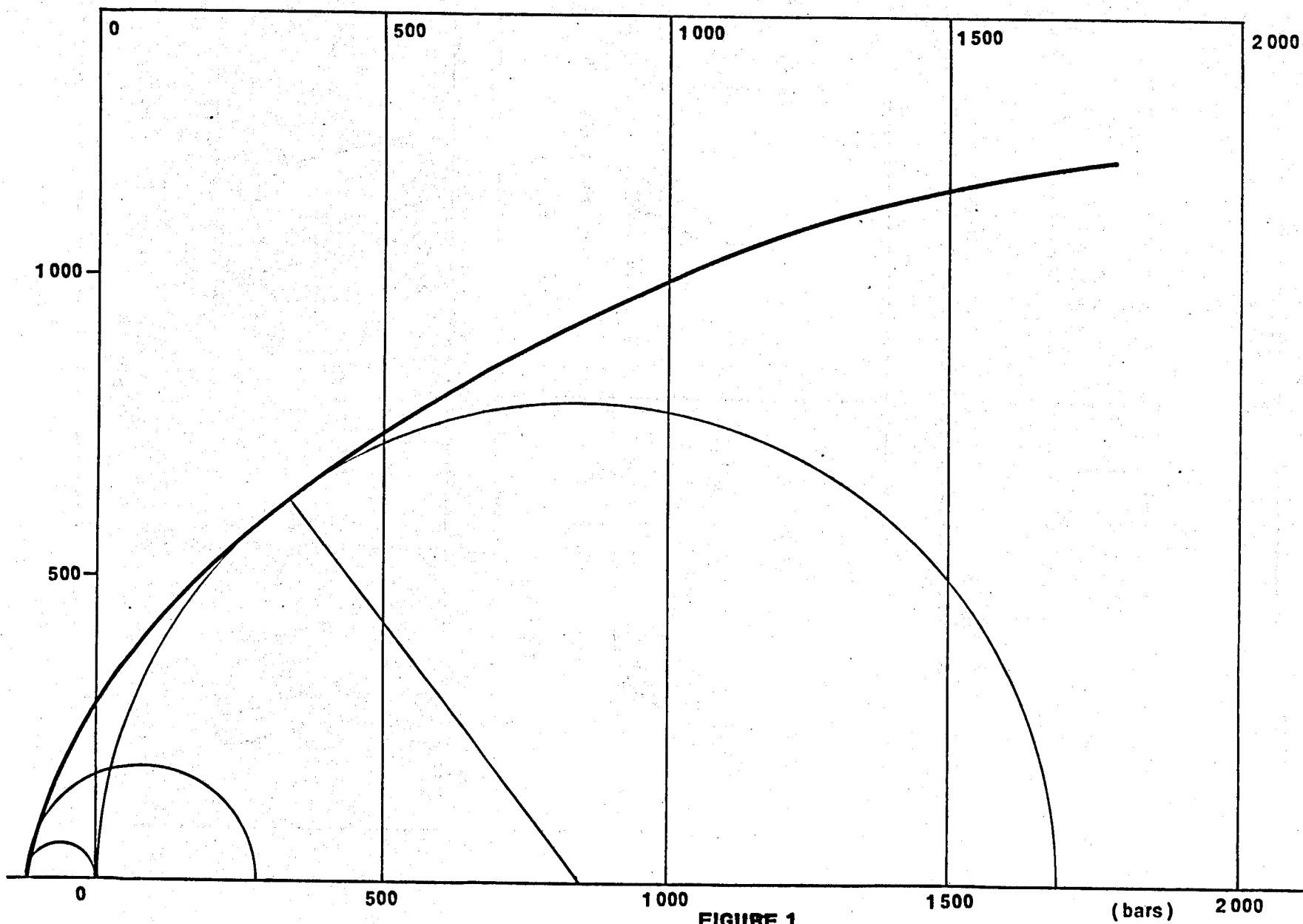


FIGURE 1

cylindrical blade

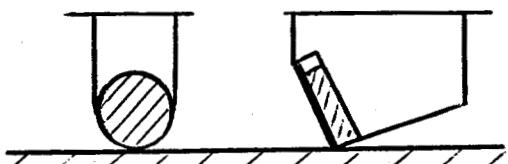


figure 2

cubic blade

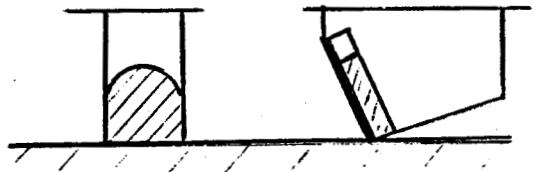


figure 3

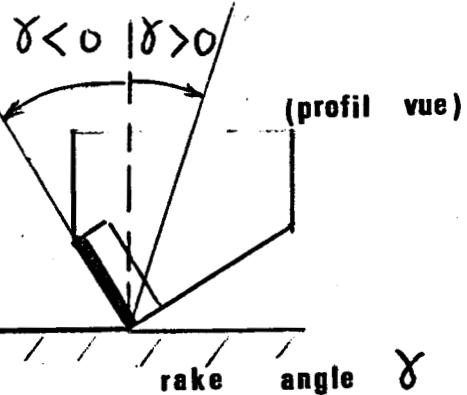


figure 4

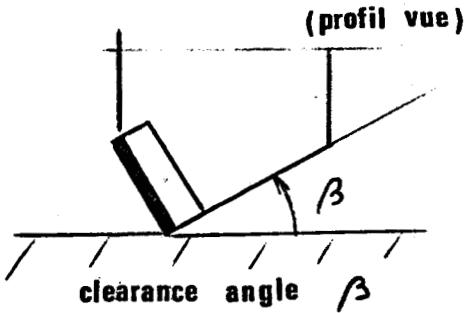
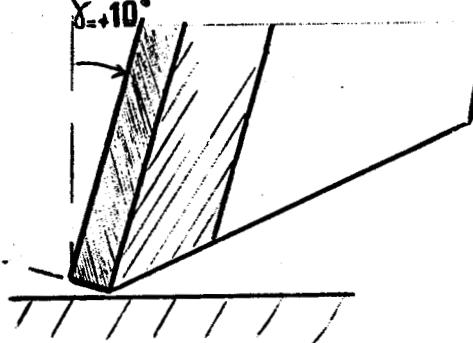


figure 5

$\gamma = +10^\circ$



$\gamma = +10^\circ$

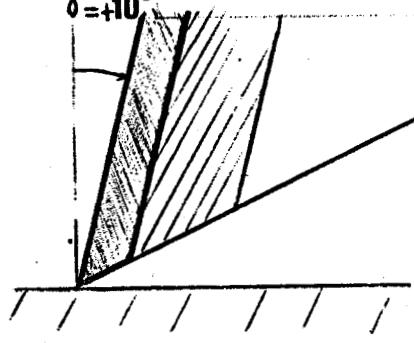


figure 6

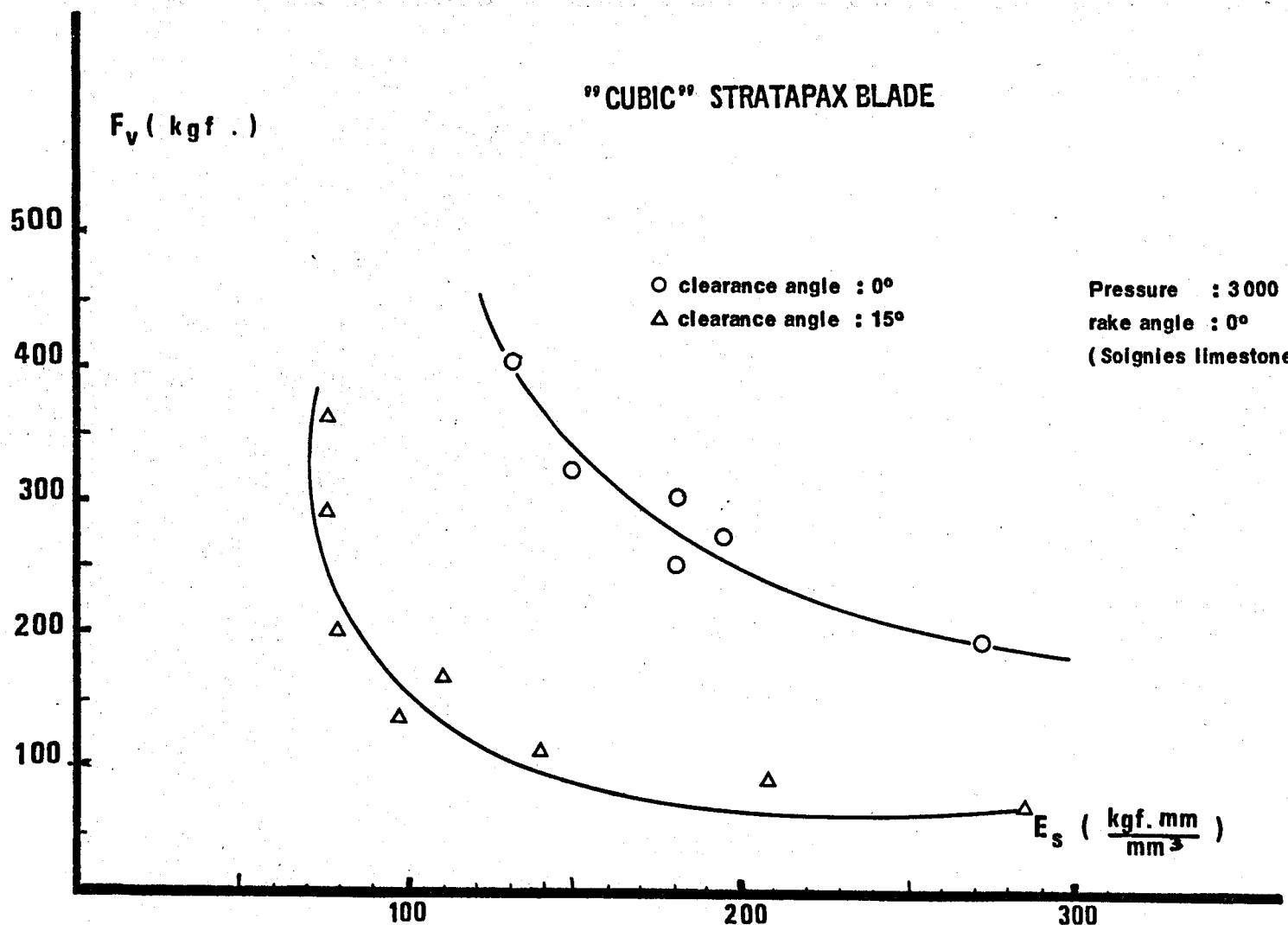


FIGURE 6 b

STRATAPAX BLADE

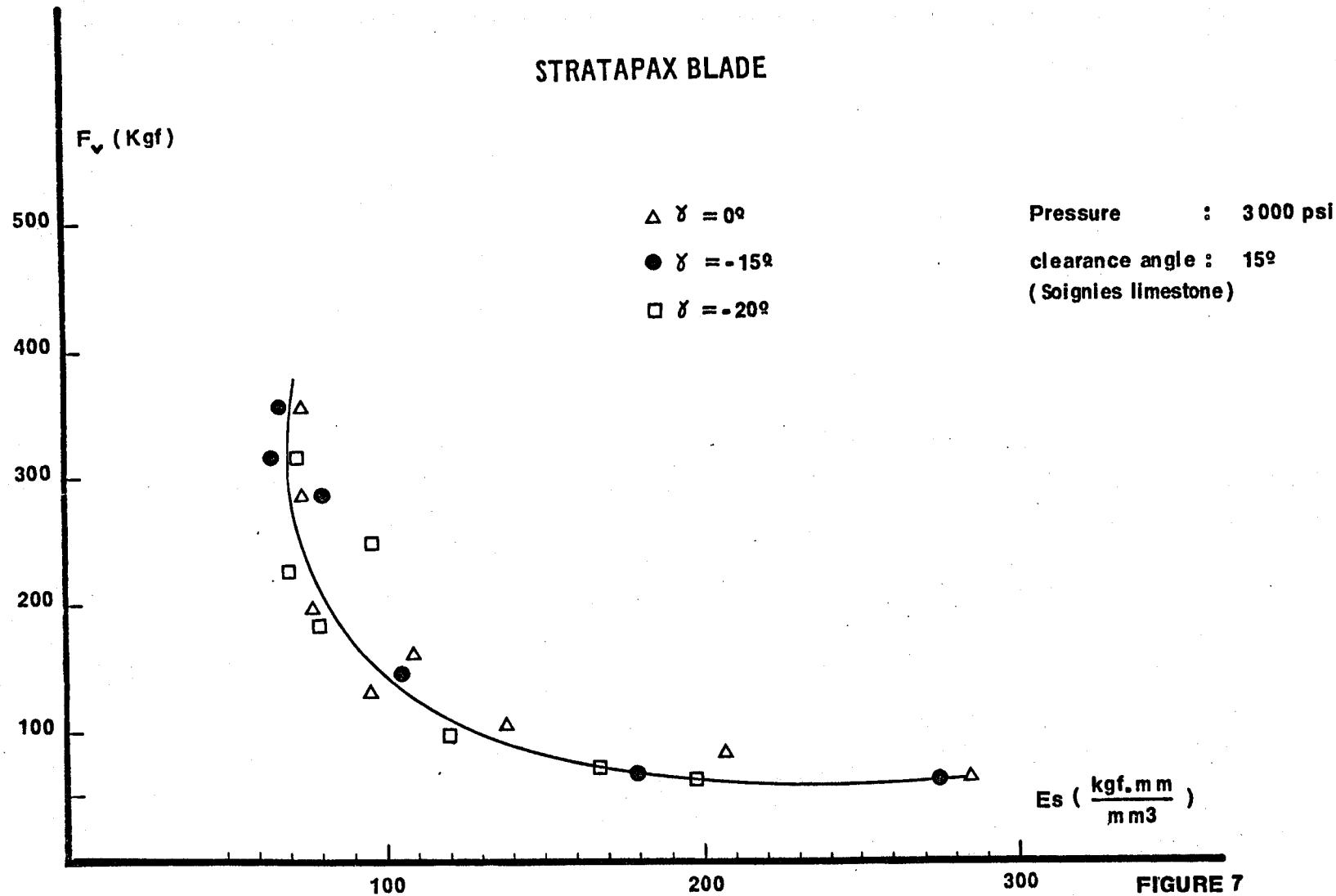
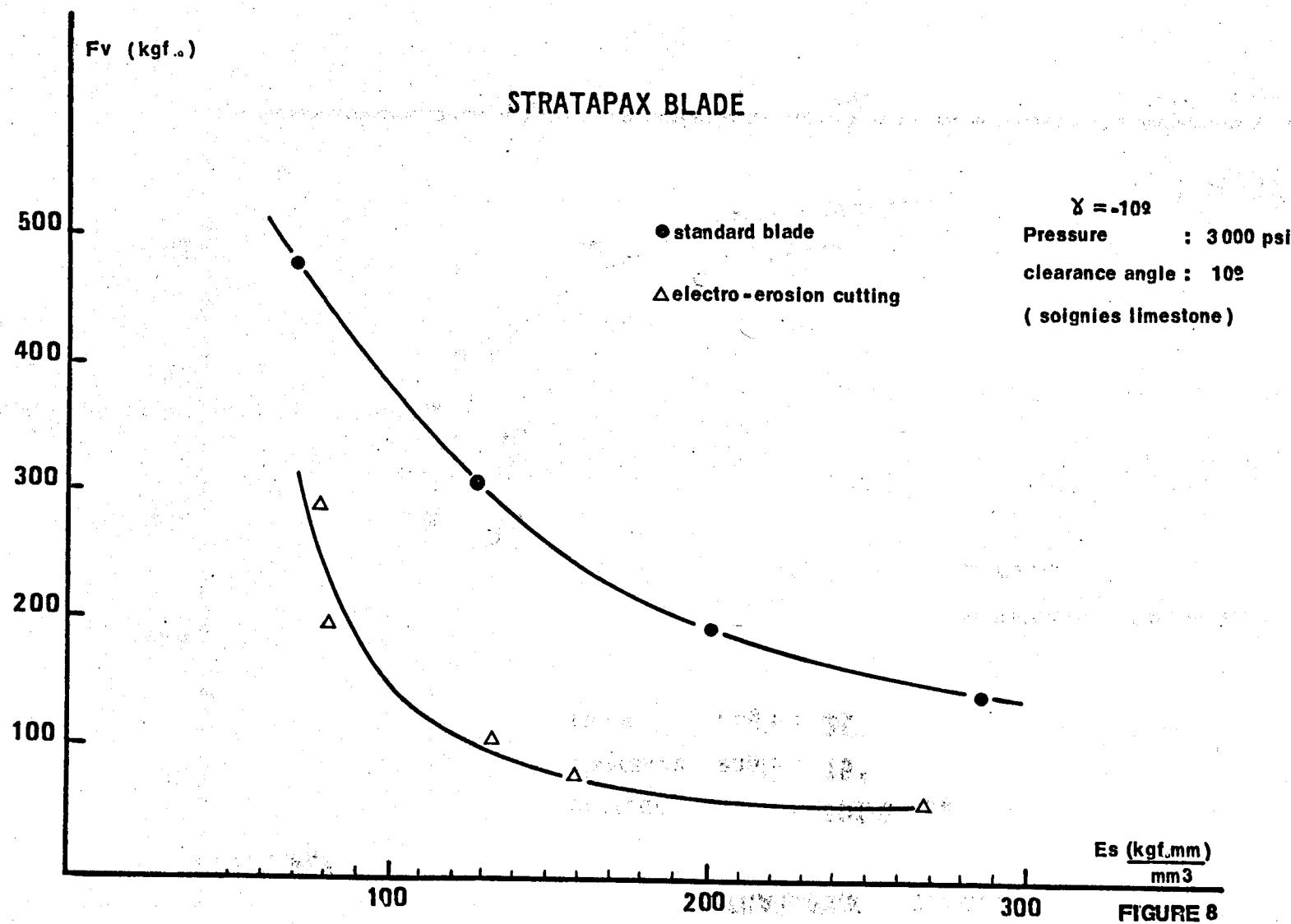
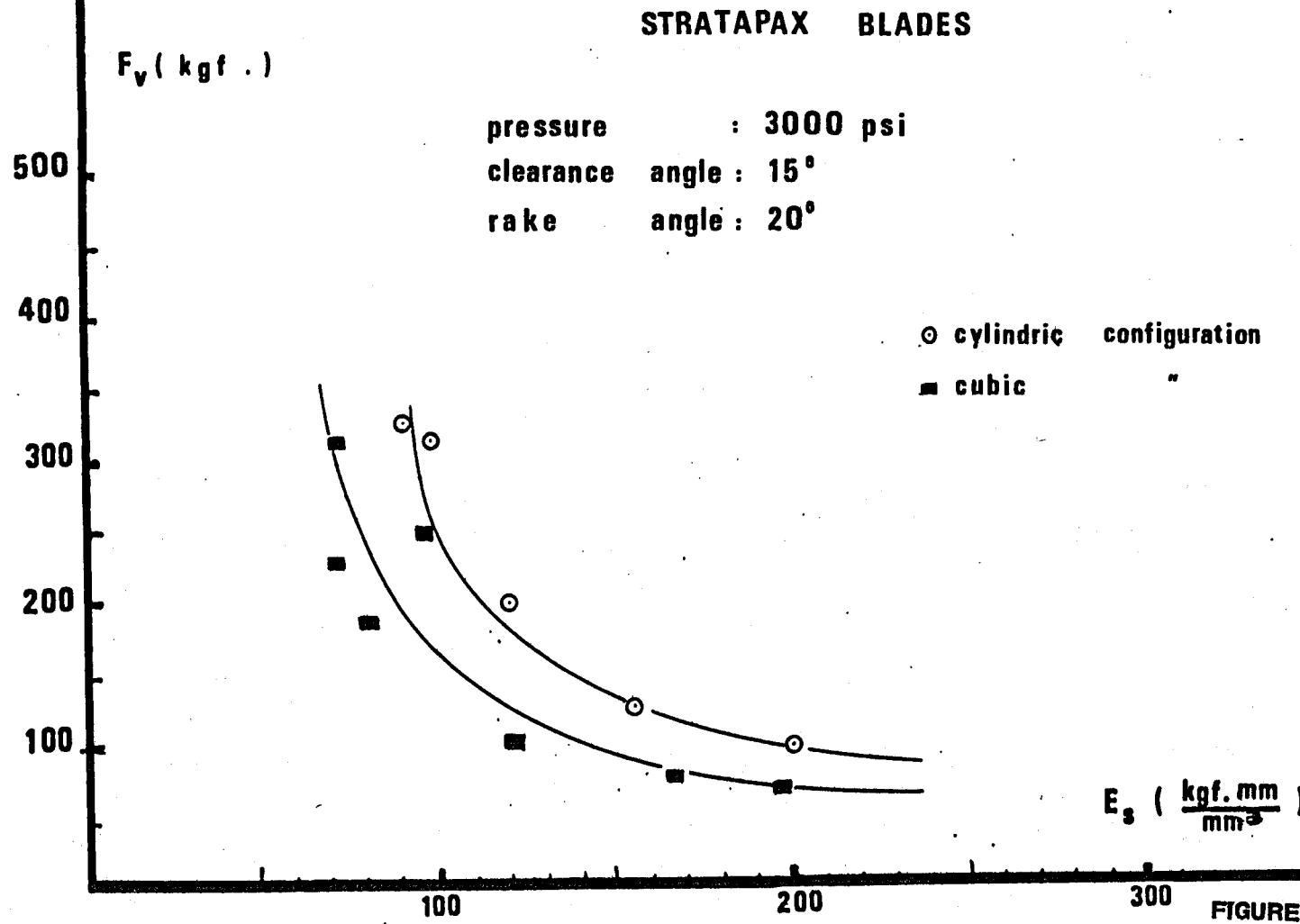
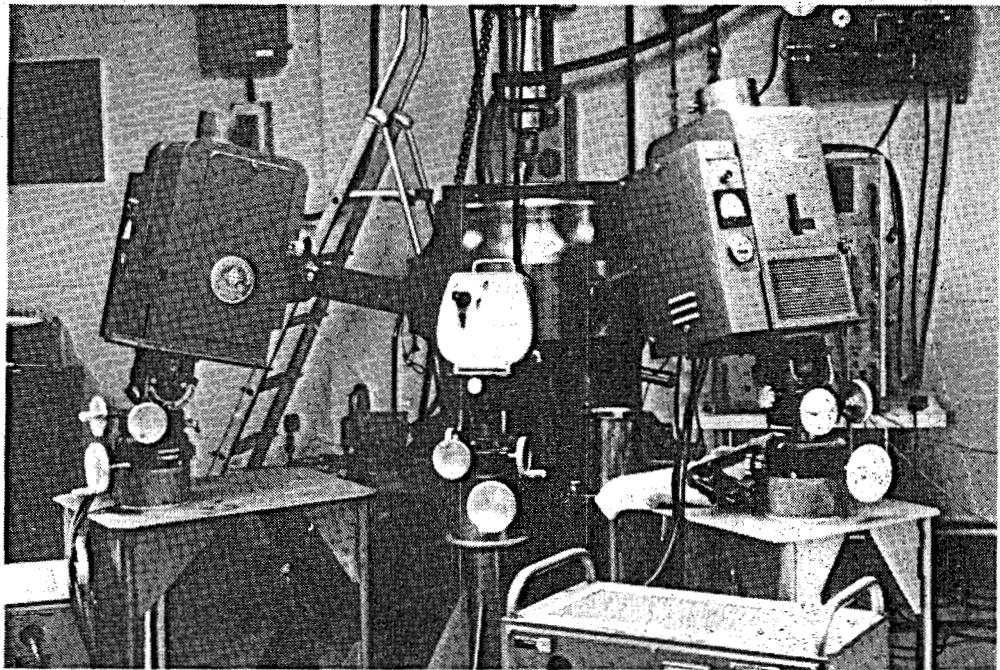


FIGURE 7

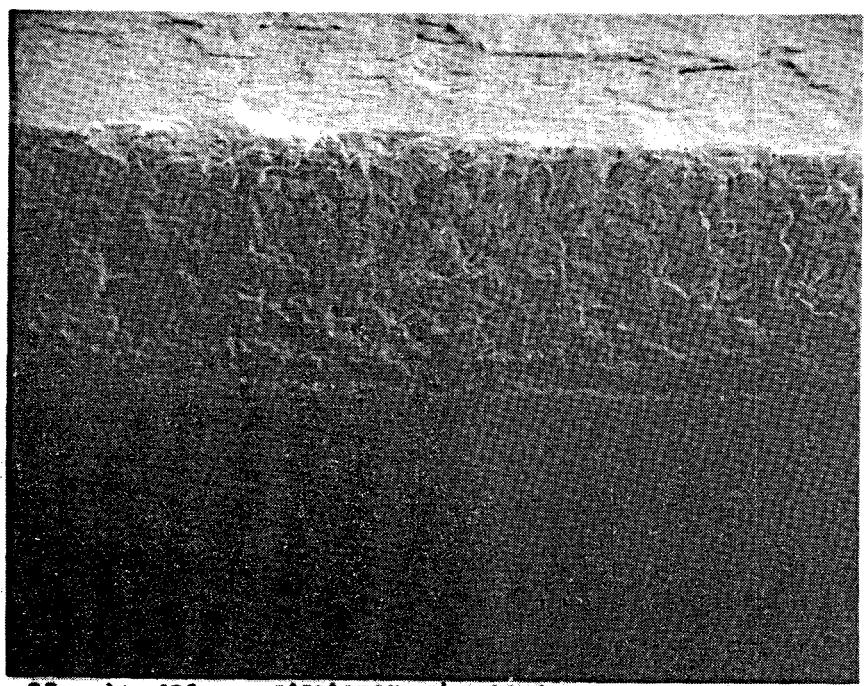






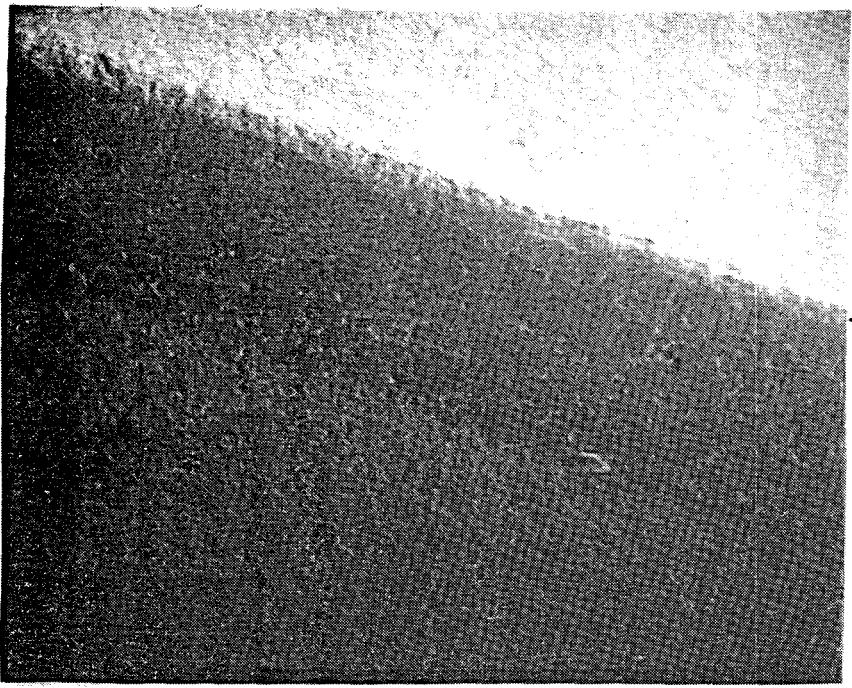
FORABILITY CELL

PHOTO 1



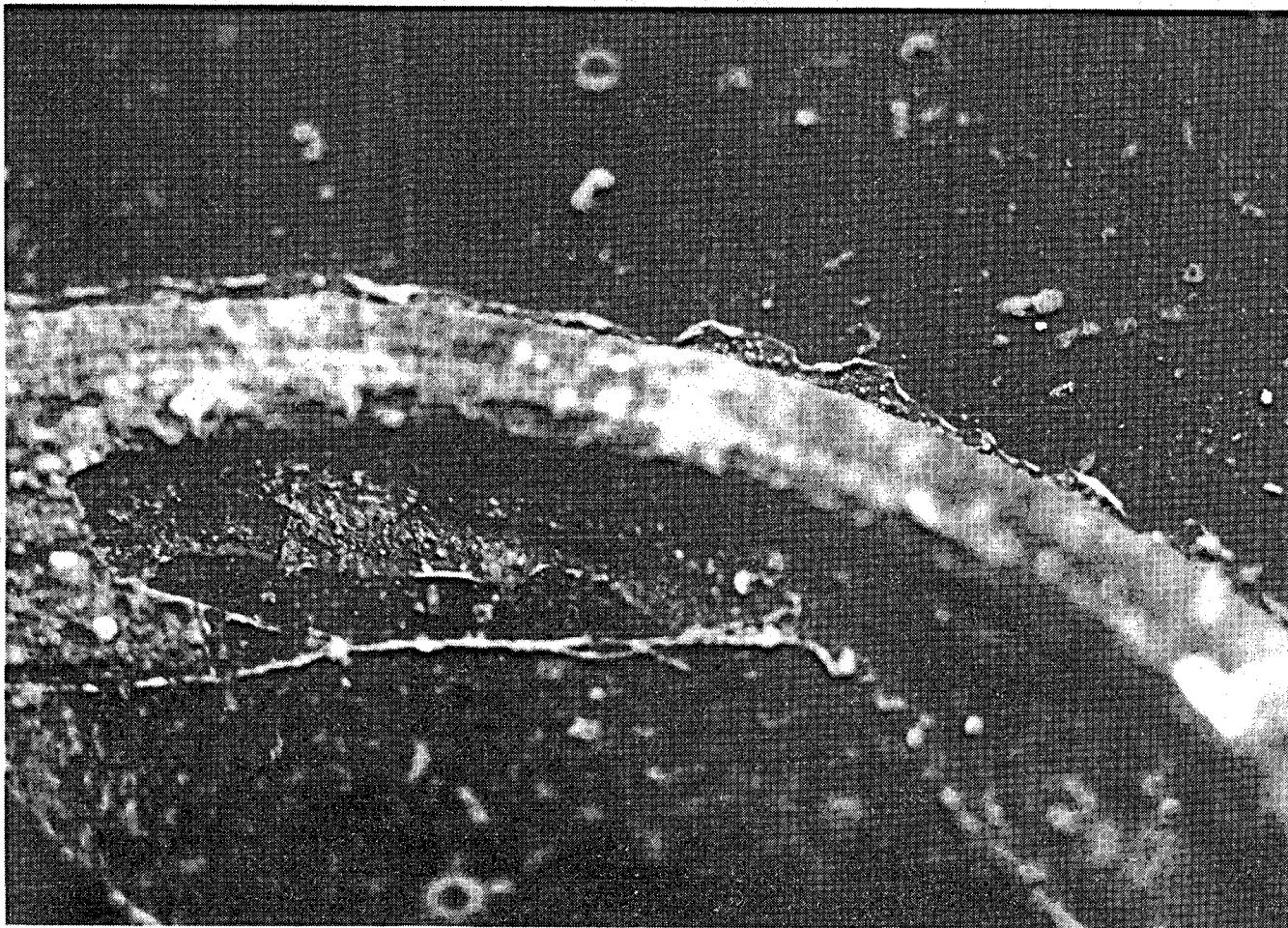
x30 $\gamma = -10^\circ$ stratapax edge blade

PHOTO 2



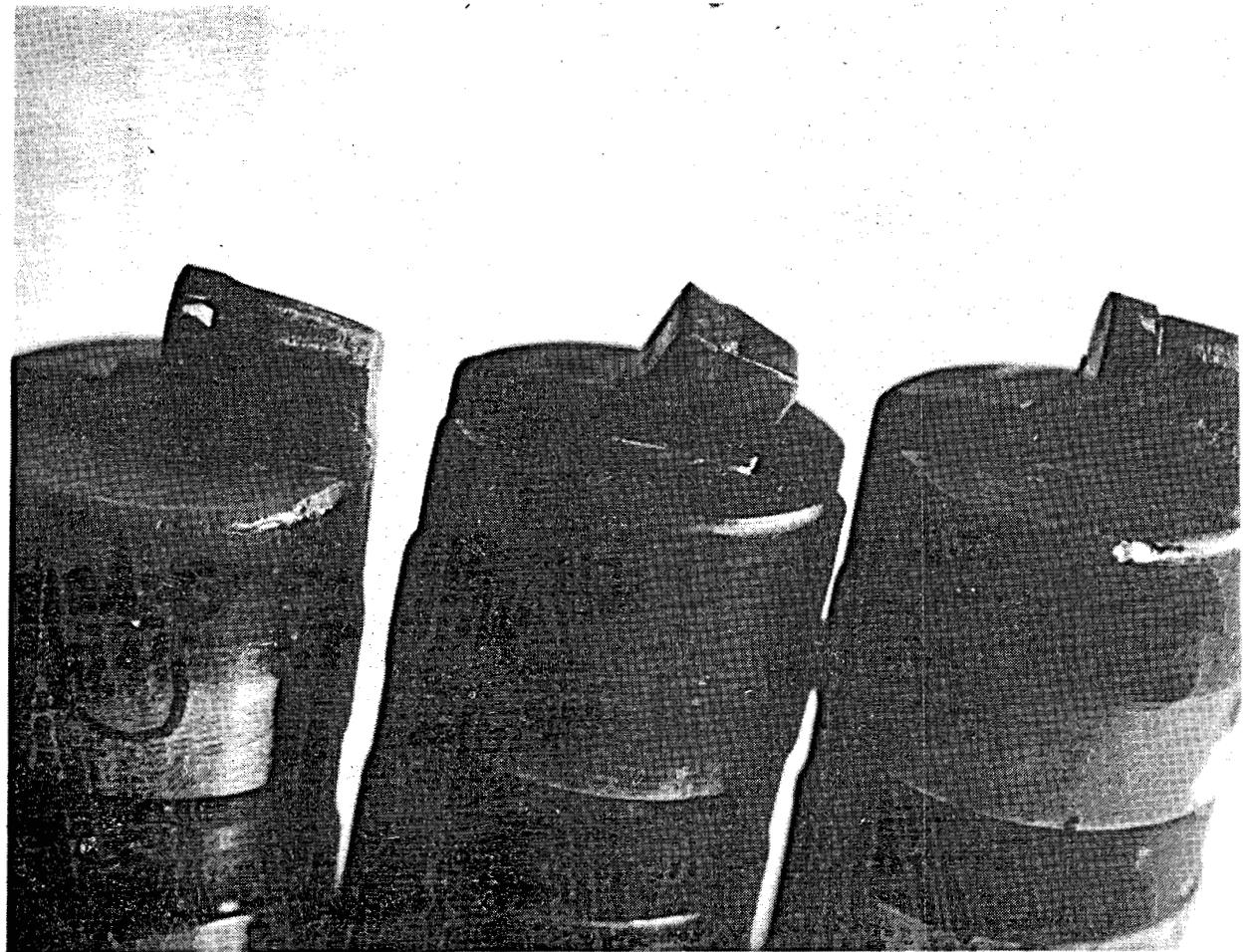
x30 $\gamma = -10^\circ$ electro-erosion cutting

PHOTO 3



ROCK SAMPLE AFTER TEST

PHOTO 4



STRATAPAX BLADES

PHOTO 5