

MACHINABILITY EVALUATION OF SELECTED HIGH GREEN STRENGTH P/M MATERIALS

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ABSTRACT

P/M parts generally require machining methods and specific tools designed to address the inherent porosity of the finished part. The composition and microstructure of sintered parts often causes machining problems and requires additives to enhance machinability. Currently, conventionally produced ferrous P/M parts have an average green strength of approximately 1500-psi. Recent technological advances with organic binders and lubricants, combined with improved compaction technology, have made it possible to produce P/M parts with enhanced green strengths. Enhanced green strength makes it possible to machine materials in the green state, thereby reducing manufacturing time and production costs. This paper examines green drilling by applying several machinability and material evaluation methods.

INTRODUCTION

One of the advantages of powder metallurgy (P/M) is the ability to fabricate high quality, complex parts to close tolerances in an economical manner. The ability to improve material utilization has been a key to the success of P/M. Although the process has excellent shape-making capabilities; some difficulty may be encountered if secondary machining operations are required. For example, accurate surfaces required for assembly may need to be turned or milled, and any holes or other re-entrants perpendicular to the compaction direction must be drilled. Intermittent cutting forces during the machining process, which result from the inherent porosity of P/M materials, can result in concentrated high stress and strain rates. Additionally, the advent of sinter-hardening P/M steels results in particle hardness values exceeding 40 HRC? Such extremely hard areas can dull cutting surfaces quickly. These factors, plus friction between the tool and the workpiece, cause local heating which is difficult to control when machining in the sintered condition. The use of liquid coolants to combat localized heating during machining is undesirable for P/M parts due to the inherent porosity. Until recently, machinability enhancement of P/M steels could only be accomplished with additions of agents such as sulfur and manganese sulfide.

Recent trends to achieve higher density levels and higher production rates indicate the need for further improvements in machinability. Achievable density is an extremely important factor in the performance of powder metallurgy components. Generally, as density is increased almost all-material properties, including strength, magnetic performance and corrosion resistance, are improved; however, many high performance materials tend to exhibit extremely poor machinability in the sintered state. Additions of machinability agents are not ideal because they adversely affect powder properties, influence dimensional change characteristics and compromise-sintered properties.

A patented material and compaction technology, ANCORDENSETM*, achieves sintered densities of 7.25 g/cm³ to 7.55 g/cm³ using conventional compaction pressures and sintering temperatures^{2,3,4,5} The ANCORDENSE technology involves the use of a specifically engineered lubricant/binder system, which acts to prevent segregation of the powder and increase lubrication of the die wall during compaction. The compaction process is carried out at an elevated temperature in the range of 265°F to 310°F with the lubricant/binder system designed to operate optimally in this temperature range. As well as providing high-density parts with outstanding physical properties, significant improvements in green strength and reduced ejection force from the die are realized. These are significantly higher green

strengths than can be obtained with conventionally produced P/M materials. Parts produced by the ANCORDENSE process are much less fragile in the green state than conventionally-produced parts, and can be subjected to significantly more handling prior to the sintering process without breaking or chipping. With such enhanced strength, also comes the opportunity to machine powder metallurgy components in the green state.

This paper evaluates the green machining process and develops guidelines for this type of machining. Drilling is the machining operation that will be examined, although other processes such as turning and milling have been demonstrated to be feasible?

A diagram of drill features is shown in Figure I with the relevant nomenclature detailed below:

- Drill point - the cutting edge of the drill
- Flutes - the grooves that are formed in the body of the drill to allow fluids to reach the point and remove chips from the workpiece
- Land - the remainder of the outside of the drill body after the flutes are cut
- Helix angle - the angle that the leading edge of the land makes with the drill axis
- Point angle - the angle between the drill lips
- Thrusting force - the force that arises from the cutting action along the lips and the extrusion and cutting forces acting at the chisel edge
- Web - the central portion of the drill body that connects the lands

PROCEDURE

A premix composition of Ancorsteel® 85HP, 2.0% nickel, 0.4% graphite, 0.6% lubricant/binder was prepared using the ANCORDENSE process. Because of its high sintered strength and good ductility, this material is considered excellent for many high performance applications; however, the poor machinability the composition exhibits in the sintered condition makes it a good candidate for green machining? The machinability of the material was evaluated by drill testing.

Testing

ANCORDENSE processed test specimens were prepared using a 1000 ton hydraulic press. Part geometry and compaction variables are listed in Table I:

Table I - Green Machining Test Variables

Test Piece Diameter	4 inches (102 mm)
Test Piece Height	1.25 inches (31.75 mm)
Test Piece Density	7.33 g/cm ³
Compaction Pressure	50 tsi (690 MPa)
Powder Temperature	290°F (145°C)
Compaction Temperature	290°F (145°C)

¹ANCORDENSE is a trademark of the Hoeganaes Corporation.

Drill test parameters are listed in Table II. A standard high speed steel (HSS) 118° drill was chosen as a reference with the remaining drills being variations of the reference in terms of surface finish, flute configuration and point angle. Preliminary laboratory testing indicated that as drill speed and feed rate were increased, the surface finish of the test pieces improved. Based on these observations, drill testing was conducted at a set drill speed of 3285 rpm and feed rate of 0.012 inch/revolution. With these parameters, drilling a through hole of the designated height can be completed in approximately two seconds.

The test procedure involved drilling five holes per piece with drills A through G listed in Table II. The following was examined:

- 1) Force exerted on workpiece
- 2) Dimensional stability

Force Exerted on the Workpiece

To determine the drilling force, a load cell was placed under the test pieces and the peak force during the drilling process was recorded. Photographs of the support fixture are shown in Figure 2. The load cell readings are plotted in Figure 3.

Drills C, E, and F exerted the lowest force on the workpiece. One common factor between these drills is that they are designed to enhance chip evacuation. Drills C and E accomplished this with polished surfaces. Chip evacuation is enhanced further with drill E by a flute design that has the heel side rolled over to allow more space for chips. Drill F has a flatter chisel area and a split point, which makes the drill more prone to fracture the material into smaller, more manageable pieces. The results indicate that efficient removal of powder from the hole during the drilling operation is an important factor in reducing drilling forces.

The geometry of a split point drill also is a factor. When grinding a split point, the clearance face of each cutting edge is given a sharp secondary relief (typically 55°) to the center of the chisel edge, thus creating a secondary cutting lip (Figure 4). The additional cutting edges, and the resulting reduction in width of the original chisel edge, act to reduce thrusting forces. 7.8

Dimensional Stability

It was important to determine to what extent distortion of the drilled holes may occur during the sintering process. Test pieces were drilled in the green condition and sintered at 2050°F (1120°C) for 30 minutes in a 75% H₂ % N₂ atmosphere. The diameter of the entrance holes. Preliminary evaluation indicated that, within the measuring resolution of a stereomicroscope, sintering the test pieces resulted in only minimal distortion of the drilled holes. Each premix composition and density combination will result in a unique hole distortion characteristic which is dependent upon material chemistry and part geometry.

Physical Appearance of Surface

For green machining to be a viable process, it is necessary for the drilled holes to be free of any areas of chipping or cracking. The holes made by the drills that exerted the lowest force on the workpiece were inspected with a stereomicroscope. Visual inspection revealed that the sample drilled with drill C, the HSS-90° polished drill, showed areas of chipping or breakout at the exit site. Clean exit surfaces with no signs of breakout were realized with the following drills:

- D) HSS-118° High helix angle
- E) HSS-118° Parabolic geometry
- F) HSS-135° Split point

The results can be explained by examining the drilling process. When a drill with a low point angle breaks through a work surface at the exit hole, the tool spindle tends to lunge and overfeed. Speeds and feed rates are temporarily unbalanced and the result is that the drill is temporarily unbalanced. The drill is not able to shear the last bit of material; it is pushed out instead (Figure 6). As the drill angle is increased, the amount of material that is pushed out decreases.[?] The results indicate that for green machining of a warm compacted material, a minimum drill angle of 118° is needed to achieve a clean exit surface, and as the point angle is increased above 118° the chance of obtaining a clean exit surface increases.

During preliminary testing, the best results in terms of force exerted on the workpiece and surface appearance were achieved with drill E (HSS-118° parabolic geometry) and drill F (HSS-135° split point). Based on these results, it was necessary to determine which drill characteristic, a split point or a parabolic geometry, was the over-riding factor for successful green machining. Drills with both characteristics were obtained in a standard condition and a with cobalt coated surface. Approximately thirty holes per piece were drilled with drills E,F,H and I (listed below) and load cell readings were recorded to determine if any reduction of the force exerted on the workpiece could be realized. These results are plotted in Figure 7.

Types of drills:

- E HSS-118° Parabolic geometry
- F HSS-135° Split point
- H HSS-135° Split point-wide land parabolic flute
- I HSS-135° Split point-wide land parabolic flute-cobalt coated

The results indicate that the highest load cell readings were realized with drill E, while the performance of drills H and I was on par with that of drill F. This discrepancy again can be explained by the difference in chisel angle. The data indicates that as expected the force explained by the difference in chisel angle. The data indicates that as expected the force exerted on the workpiece decreases as the drill chisel angle is increased to 135°, although acceptable results can be achieved with an angle of 118°.

SEM Analysis

Scanning electron microscopy (SEM) analysis was done with samples from drills E, F, H, and I to help quantify the test results.

Internal Surface of Drilled Holes

SEM photographs of the internal surface of the drilled holes are shown in Figures 8 and 9. The photographs indicate that the best surface finish is achieved with drill F, (HSS-135° split point) and the poorest with drill I (HSS-135° split point-wide land parabolic flute-cobalt coated).

The hole produced by drill E (118° parabolic flute geometry) shows a fairly clean surface; however, when the entire area is scanned, there are a fair number of pitted areas present in this sample. This is most likely due to the higher thrusting

force associated with the lower angle drill.

The hole produced by drill F (135° split point) shows striations on the cutting surface which are fine and evenly distributed. Closer examination reveals only very small areas of pitting where it appears that powder particles have been pulled out from the internal surface. No areas of micro cracking were observed.

No benefit in the surface finish was realized with drill H (HSS-135° split point-wide land parabolic flute). This was likely due to the land thickness. It is felt that the enhanced land thickness negated any positive effects of the parabolic geometry.

The photographs of the hole produced by drill I (HSS 135° split point-wide land parabolic flute-cobalt coated) appear very rough and contains large, deep pits associated with powder being pulled from the surface. The metal appears to have smeared, which indicates that using the selected drill speed and feed rate, drill I was not efficient at cutting the material. High magnification photographs of this sample also show possible areas of micro cracking. This seems to indicate that drill coatings such as cobalt may not be beneficial for green machining.

Powder Removed from the Hole During Drilling Process

SEM photographs of the powder that was removed from holes during the drilling operation can be seen in Figures 10 and 11. The Low magnification photographs show a high degree of particle irregularity associated with the powder removed by drill E (Figure 10) and drill I (Figure 11). The particle size distribution for these samples is very wide and they contain a higher percentage of large particles than the powder removed by drill F (Figure 10) and drill H (Figure 11). This can be explained by examining the drill geometry. As was previously stated, a flatter point such as that for the 135° split point drills, is more effective at controlling chip size because it fractures the material into smaller pieces. It is felt that the cobalt coating on drill I negated any beneficial effects of the flatter chisel point.

Each sample contained a small percentage of powder particles with visible areas of shearing. The powder removed by drill E (HSS-135° split point) contained fewer sheared particles than the other samples that were examined. The powder also shows less intense surface striations, which is indicative of a lower drilling force.

Overall, the SEM analysis indicates that split point geometry is the most important drill characteristic for successful green machining.

Machinability versus green strength

The effect of green strength level on successful green machining was evaluated. Mixes were prepared those provided green strengths ranging from approximately 4000 psi to 9500 psi. Property information for the various test materials is detailed in Table III.

The test mixes (M1 through M5) were prepared in the laboratory using various proprietary lubricant/binder combinations. It is important to note that although the mixes have green densities ranging from 7.15 g/cm³ to 7.37 g/cm³, the relationship between green density and green strength is not direct; rather, the green strength is a function of the organic lubricant and material processing. The goal was to determine whether green strength or the lubricant/binder system was the prevailing factor for successful green machining. Drill testing was done with a HSS-135° split point drill with a feed rate of 0.012 inches/revolution and drill speed of 3285 rpm. A drill size of 0.1875 inches was used with a corresponding sample size of 3.5 x 0.5 x 0.5 inches. SEM photographs of the internal surface of the drilled holes can be seen in Figures 12 through 14.

More testing needs to be done to determine if the drilling guidelines from preliminary laboratory testing can be transferred successfully to a production setting.

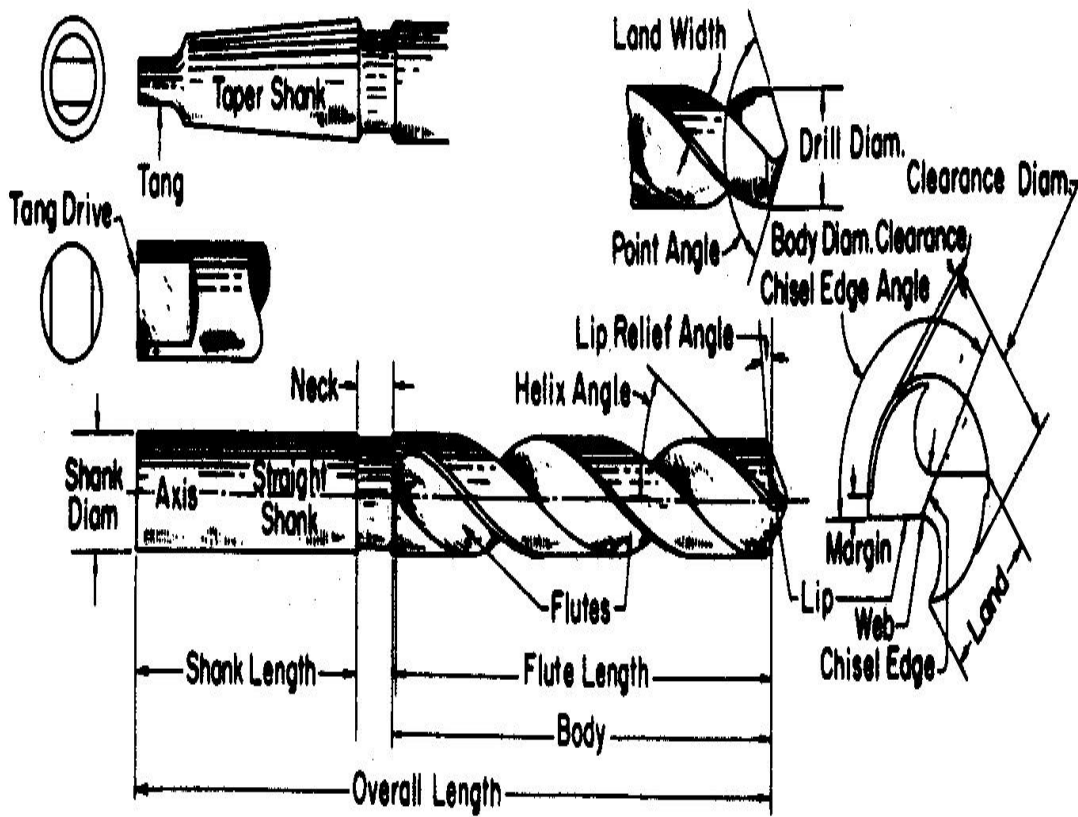
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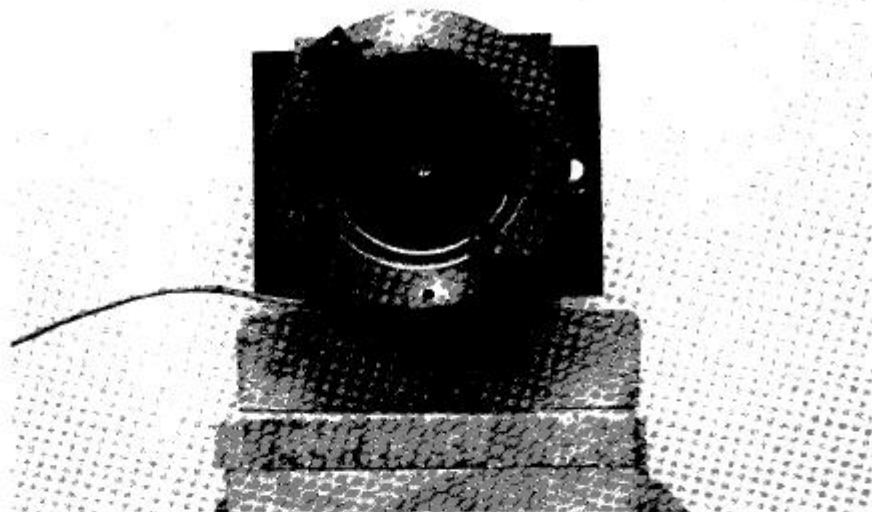
The authors wish to acknowledge the support of Hoeganaes Corporation in the preparation of this paper. They are particularly grateful to P. Meutz for his assistance with all aspects of testing, G. Golan and S. Kolwicz who were instrumental in performing all the necessary SEM analysis and H. Phan, P. Kremus, B. Quirt, V. Kuzmicz, and J. DiLeonardo who prepared all the mixes that were used for this study.

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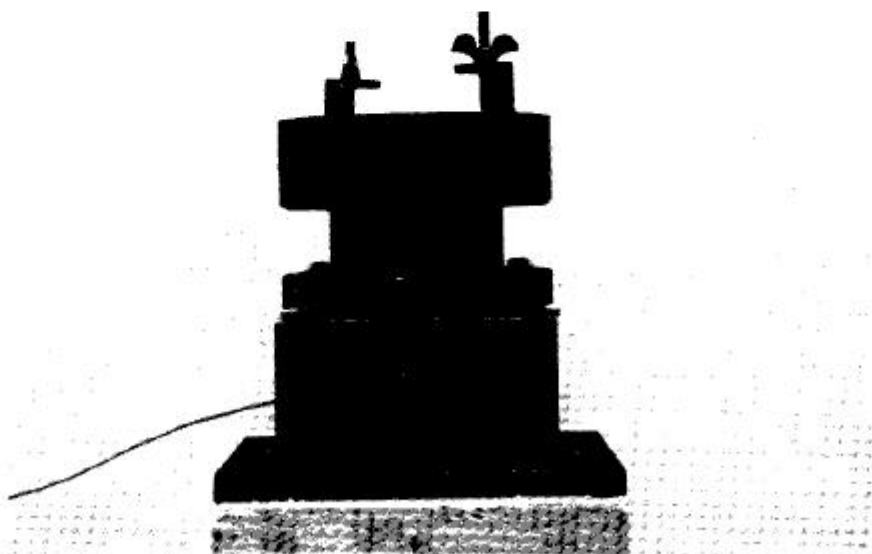
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- Lips - the angle between these denotes the angle of the drill
- Heel - the inside portion of the land facing the drill body





(a) Top View



(b) Side View

Figure 2 - Photographs of Support Fixture Used for Drill Testing

Table II : Green Machining Drilling Parameters

Drilling Parameters	
Drill Speed	3285 rpm
Feed Rate	0.012 inch/revolution
Drill Diameter	0.375 inch (9.5 mm)
Hole Type	Through Hole
Drill Types	A Standard HSS-118° B HSS-118° Polished surface C HSS-90° Polished surface D HSS-118° High helix angle E HSS-118° Parabolic geometry F HSS-135° Split point G HSS-118° TiN coated

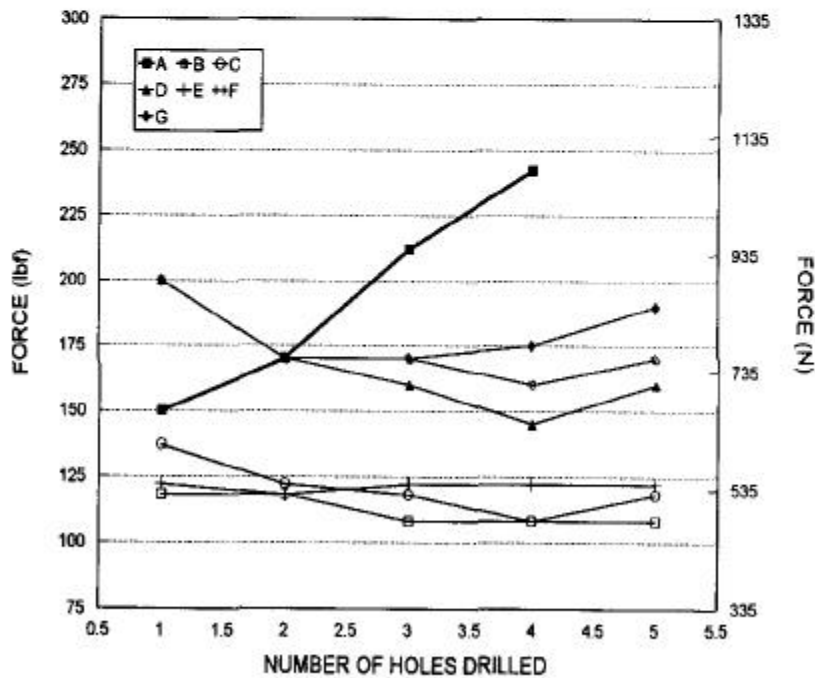


Figure 3 - Evaluation of Drilling Force vs. Type of Drill

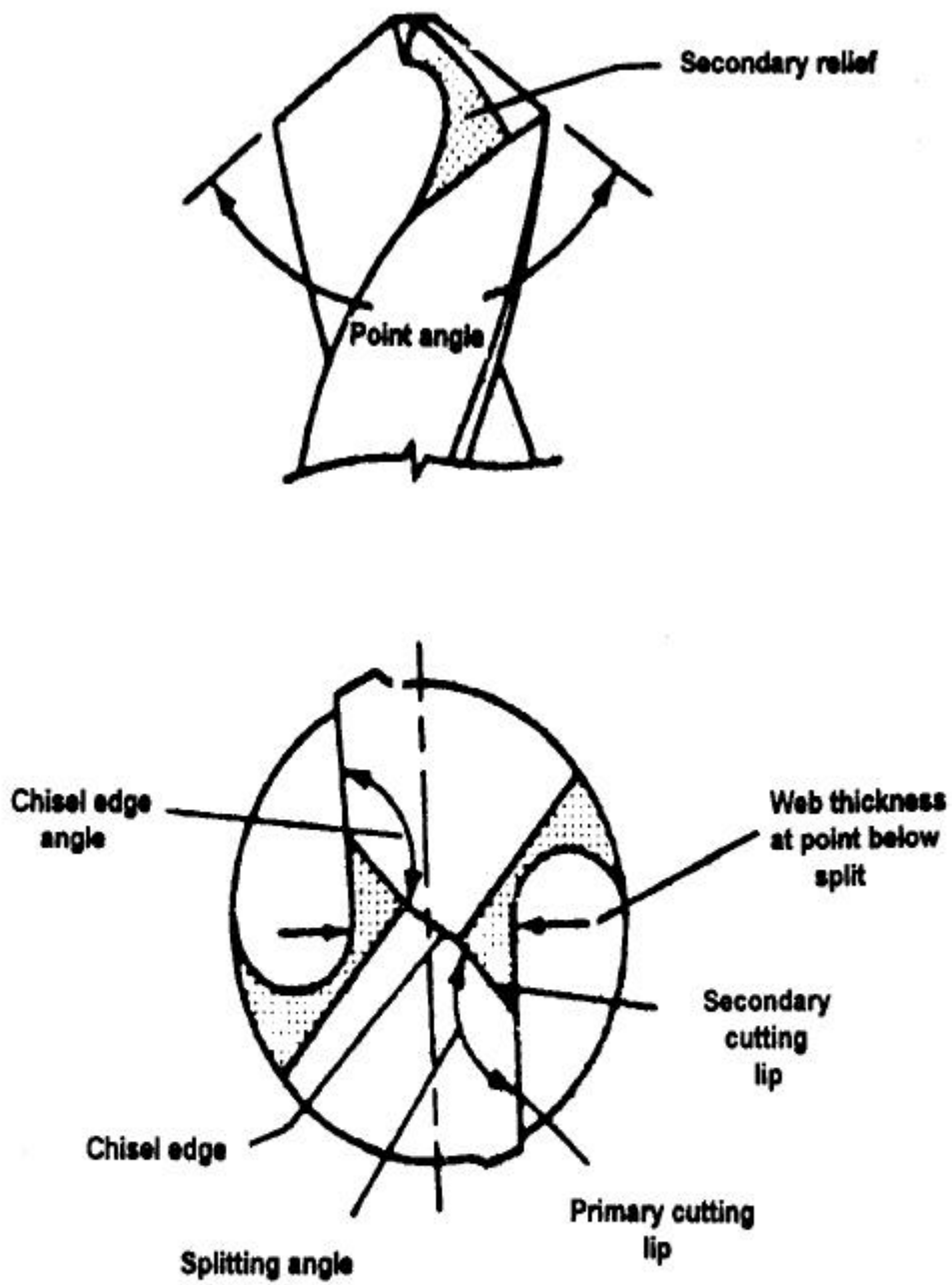


Figure 4 - Schematic of Split Point Drill

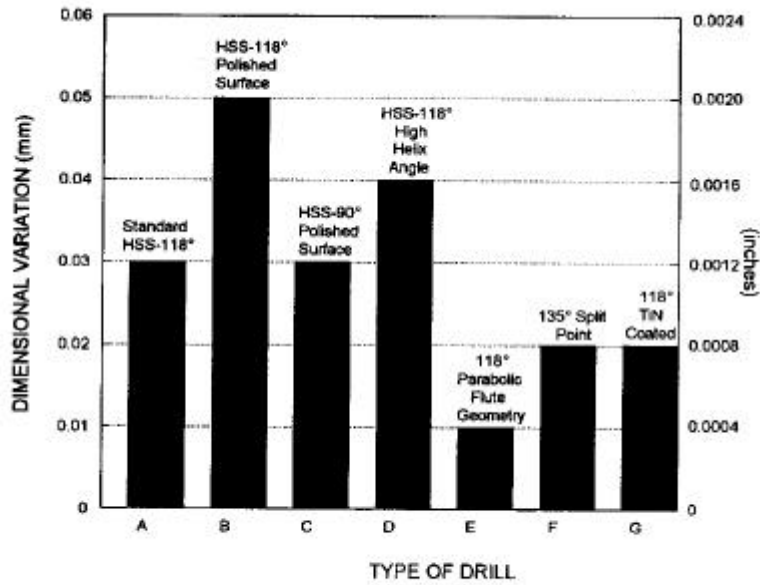


Figure 5 - Dimensional Variation of Entrance Hole - Green Diameter Minus Sintered Diameter

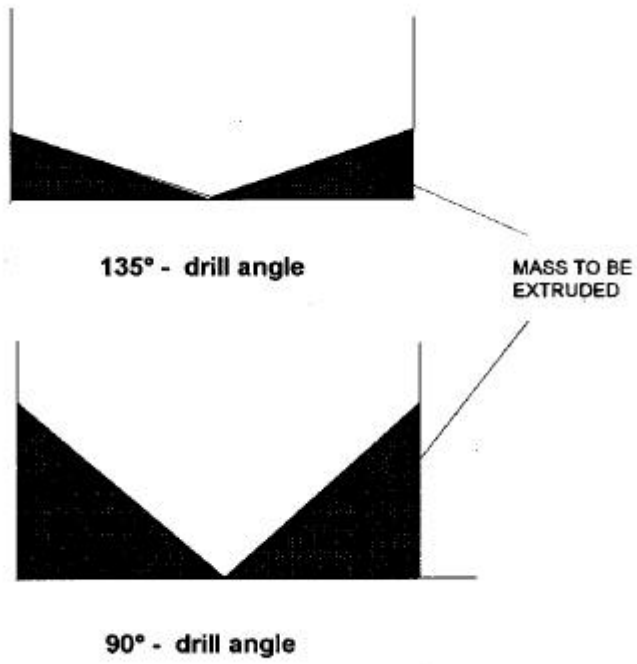
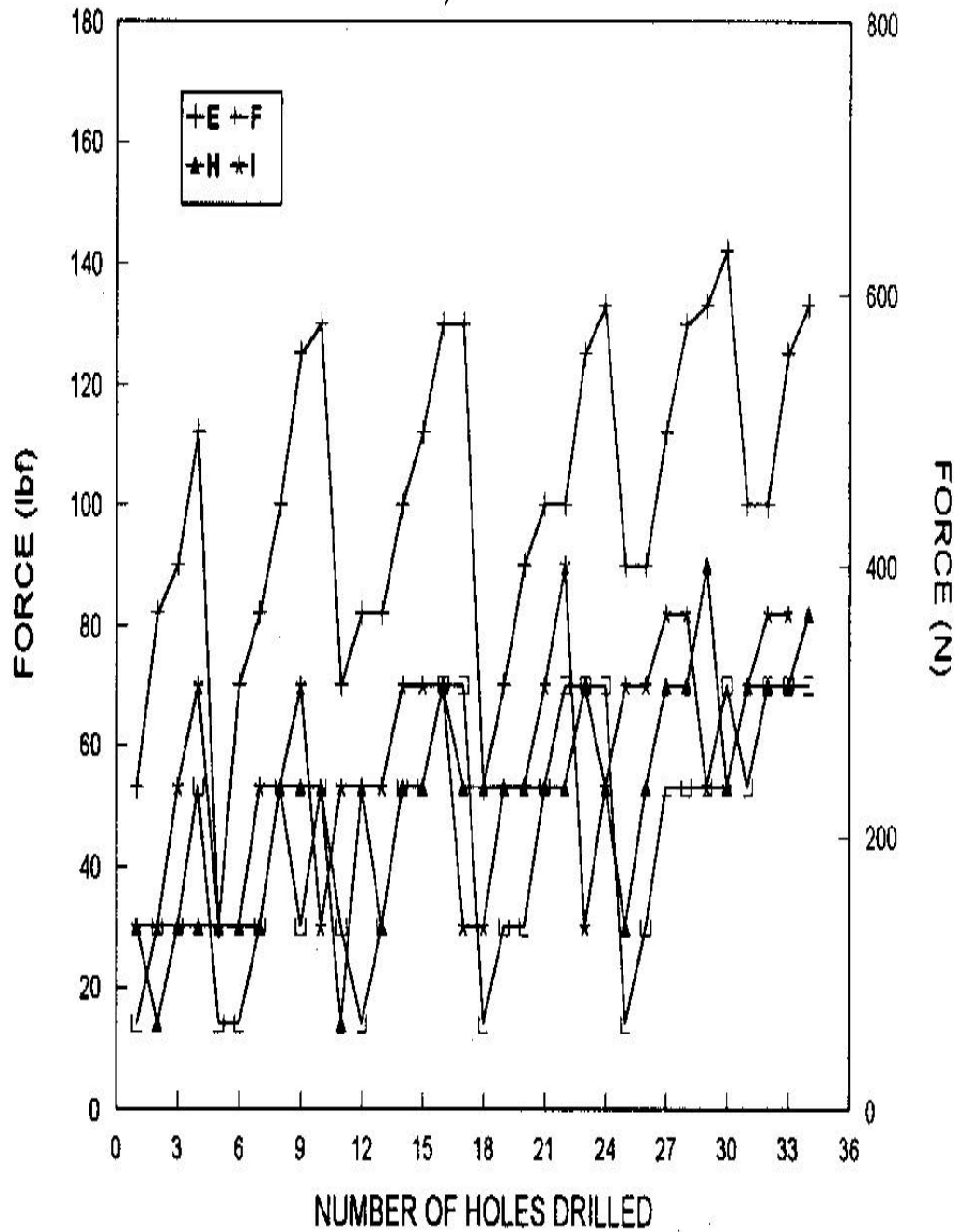
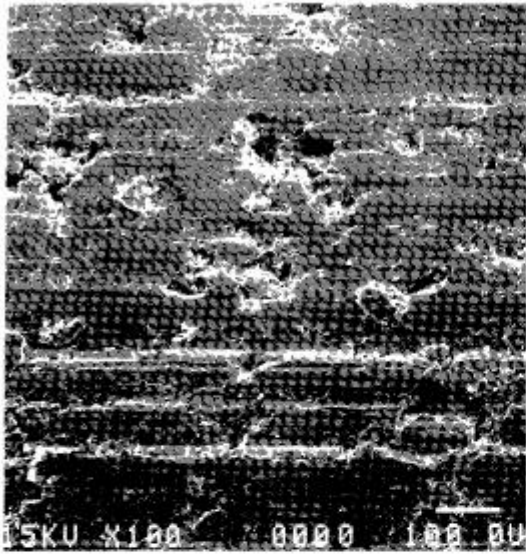
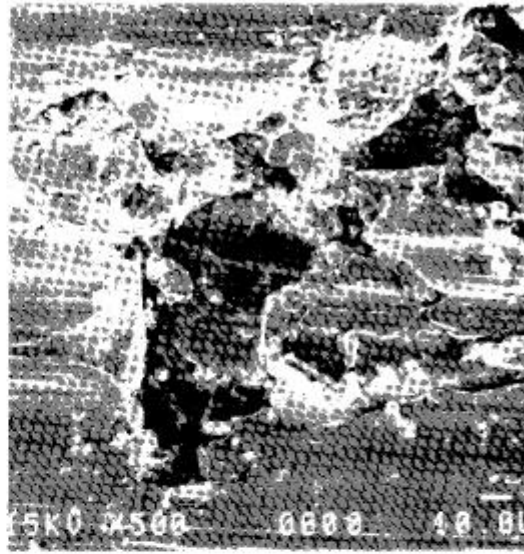


Figure 6 - Relationship Between Point Angle and Potential for Breakthrough at Exit Site

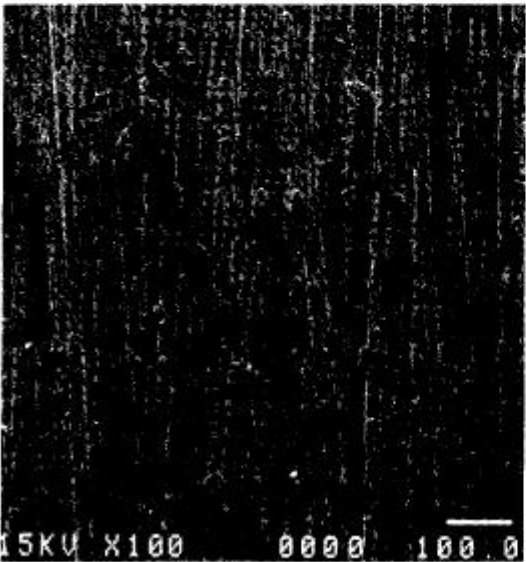




(a) HSS-118° Parabolic geometry-100x
(drill-E)



(b) HSS-118° Parabolic geometry-500x
(drill-E)



(c) HSS-135° Split point-100x (drill-F)



(d) HSS-135° Split point-500x (drill-F)

Figure 8 - SEM Photographs - Internal Surface of Drilled Holes



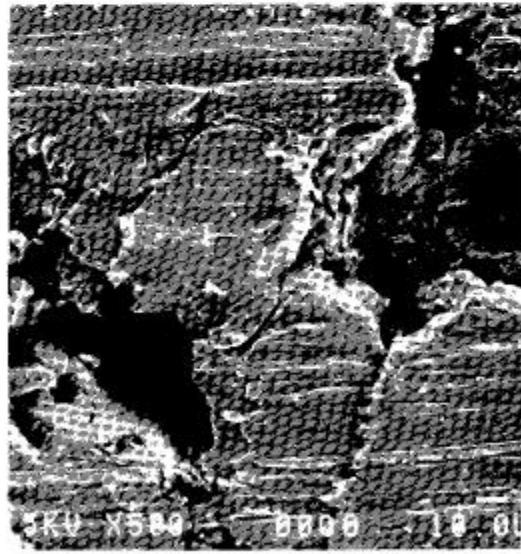
(a) HSS-135° Split point-wide land parabolic flute-100x (drill-H)



(b) HSS-135° Split point-wide land parabolic flute-500x (drill-H)

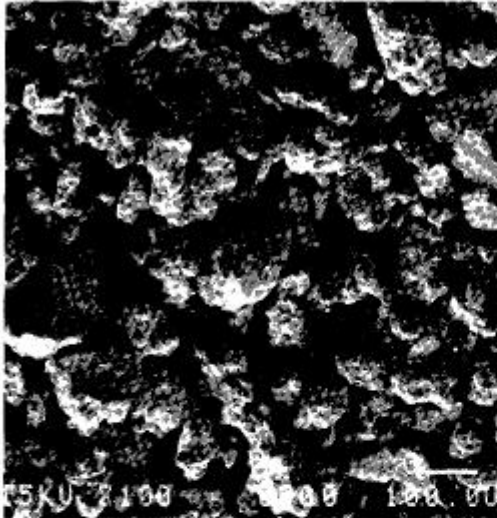


(c) HSS-135° Split point-wide land parabolic flute-cobalt coated-100x (drill-I)

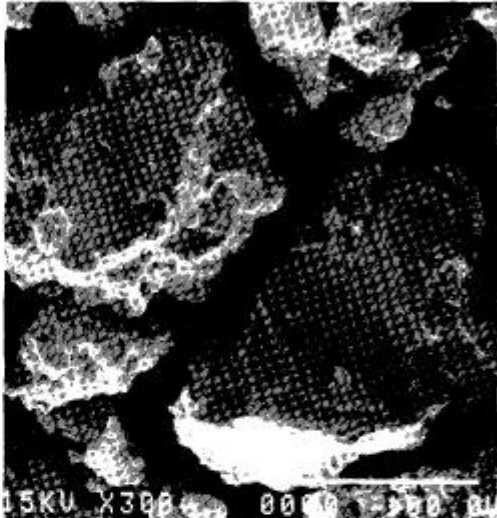


(d) HSS-135° Split point-wide land parabolic flute-cobalt coated-500x (drill-I)

Fig 9 - SEM Photographs - Internal Surface of Drilled Holes



(a) HSS-118° Parabolic geometry-100x (drill-E)



(b) HSS-118° Parabolic geometry-300x (drill-E)

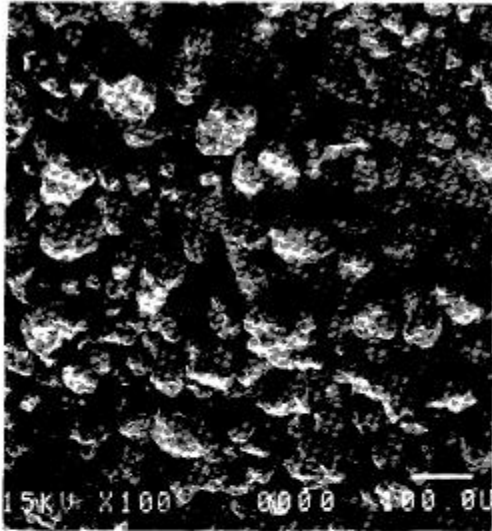


(c) HSS-135° Split point-100x (drill-F)



(d) HSS-135° Split point-300x (drill-F)

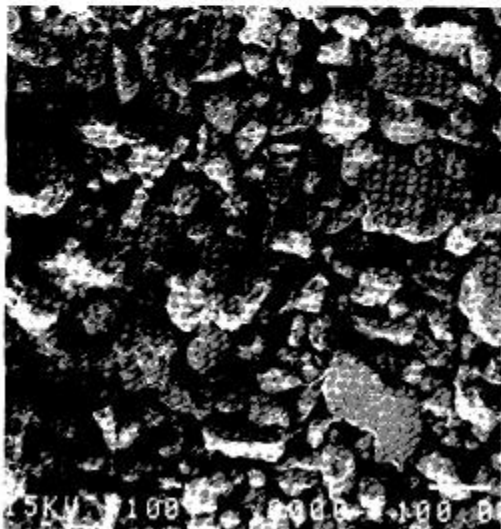
Figure 10 - SEM Photographs - Powder Drillings



a) HSS-135° Split point-wide land parabolic flute-100x (drill-H)



b) HSS-135° Split point-wide land parabolic flute-300x (drill-H)



c) HSS-135° Split point-wide land parabolic flute-cobalt coated-100x (drill-I)



d) HSS-135° Split point-wide land parabolic flute-cobalt coated-300x (drill-I)

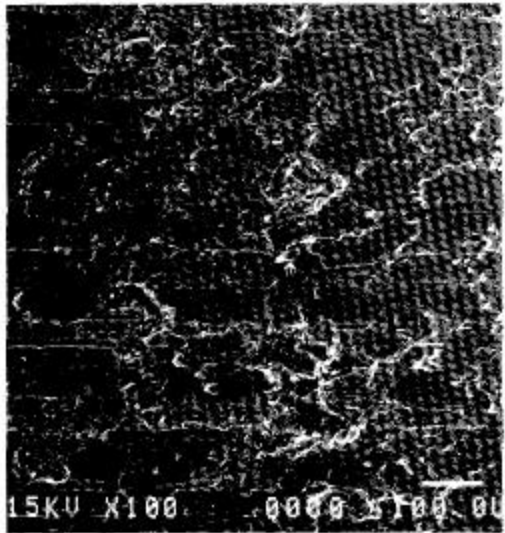
Figure 11- SEM Photographs - Powder Drillings



(a) M-1 - 100x



(b) M-1 - 500x

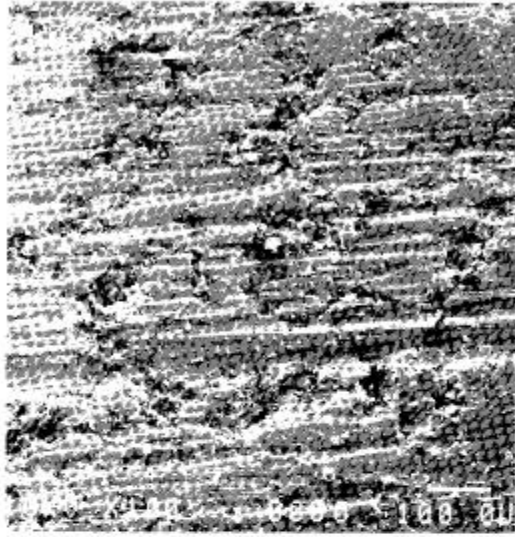


(c) M-2 - 100x



(d) M-2 - 500x

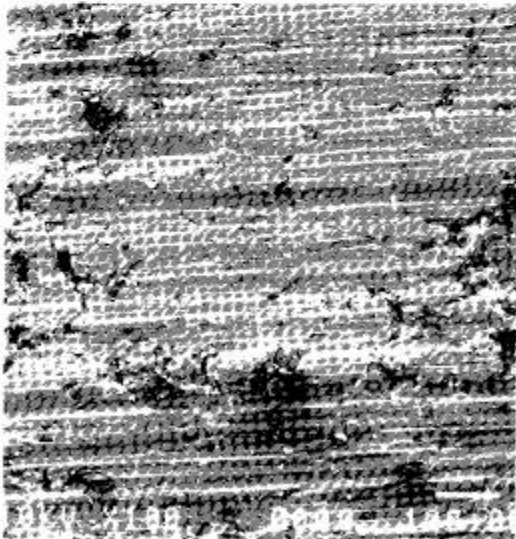
Figure 12 - SEM Photographs - Internal Surface of Drilled Holes



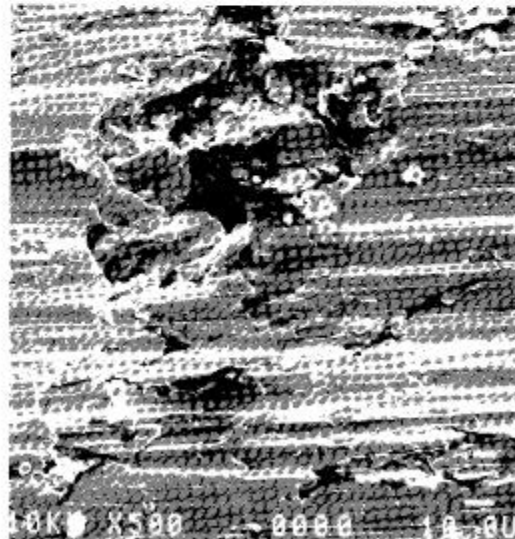
(a) M-3 - 100x



(b) M-3 - 500x

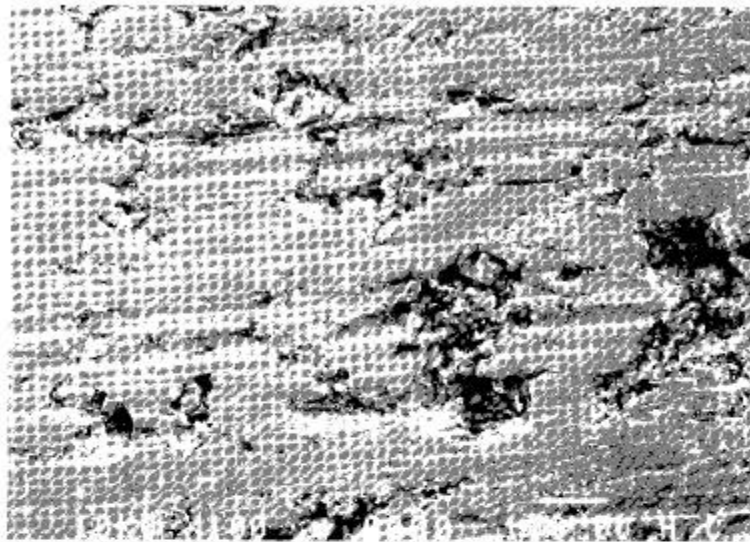


(c) M-4 - 100x

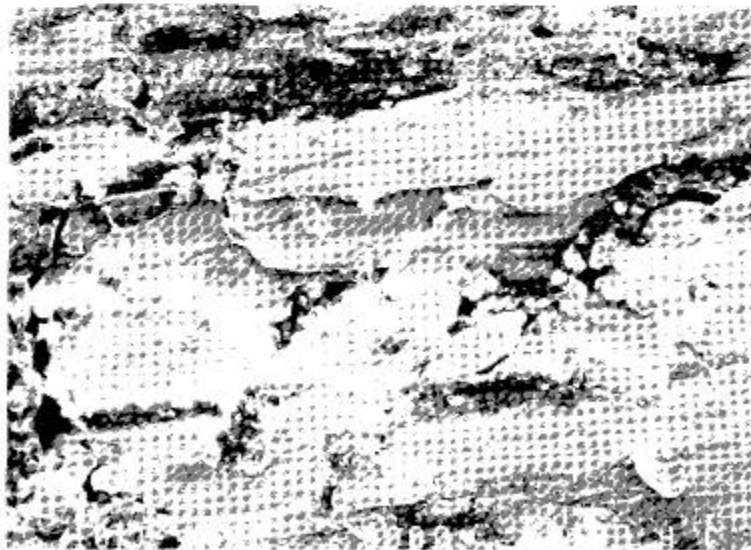


(d) M-4 - 500x

Figure 13 - SEM Photographs - Internal Surface of Drilled Holes



(a) M-5 - 100x



(b) M-5 - 500x

Figure 14 - SEM Photographs - Internal Surface of Drilled Holes