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A NEW DRMS DRILLING TECHNIQUE FOR THE LABORATORY

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Abstract

The Drill Resistance Measuring System (DRMS) is used with drill bits that have two main cutting edges, which do most of the cutting, and two lateral cutting edges, which are engaged when the drill bit vibrates or wobbles. The two main cutting edges do not meet at a point and so a partially non-cutting edge (called chisel edge) exists between the two cutters. The mechanics of drill bit penetration involve two radically different phenomena: the cutting edges bite into the material and cut it off; the chisel edge (and particularly the part nearest to the axis of the tool) indents the material pushing it away from the tip of the drill bit. This localized process of cold-forming is responsible for an important part of the thrust force needed to drill into the material.

In this paper we propose a new technique for the use of the DRMS instrument in the laboratory that does away with the problems associated with the chisel edge. The technique proposed, based on pilot holes, also allows the blowing of air during drilling and we verify the gains in terms of avoiding the inordinate resistance increase caused by the packing of

stone dust during drilling. Finally we note that since the use of pilot holes reduces the thrust needed for drilling, the DRMS equipment may now be used to test harder zones or materials that are presently out of its measuring range.

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Summary

The Drill Resistance Measuring System (DRMS) is used with drill bits that have two main cutting edges, which do most of the cutting, and two lateral cutting edges, which are engaged when the drill bit vibrates or wobbles. The two main cutting edges do not meet at a point and so a partially non-cutting edge (called chisel edge) exists between the two cutters. The mechanics of drill bit penetration involve two radically different phenomena: the cutting edges bite into the material and cut it off; the chisel edge (and particularly the part nearest to the axis of the tool) indents the material pushing it away from the tip of the drill bit. This localized process of cold-forming is responsible for an important part of the thrust force needed to drill into the material.

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dust during drilling. Finally we note that since the use of pilot holes reduces the thrust needed for drilling, the DRMS equipment may now be used to test harder zones or materials that are presently out of its measuring range.

1-Introduction

The Drilling Resistance Measuring System (DRMS) is basically a power drill with constant feed and a force transducer that measures the thrust as a function of the drilling depth. It does not fully qualify as a non-destructive device, but since the intrusion is comparatively small- typically a 5mm hole- and the valuable data obtained cannot be duplicated by other means, it is generally considered an acceptable practise. It may be called a quasi-non-destructive device and conveniently discussed with other non-destructive techniques.

The equipment was originally developed through an European Project but the version now available on the market incorporates later improvements. General information about the DRMS can be obtained in several publications [1, 2] and also in the Internet (server.icvbc.cnr.it/drilling/index.htm).

The system was designed to accept normal drill bits. Originally, the drill bits used were basically from a current conical-tip type available in the market but re-sharpened to specifications. Presently, flat-tip diamond bits are custom made for the equipment. The rationale for the flat tip shape is the need to attain a steady state as soon in the penetration as possible, and thus be able to easily compare the characteristics of materials near the surface to those deeper inside. For the sake of generality, however, we shall deal primarily with the mechanics of conical-tip drilling, since flat tip bits are just a particular case in which the point angle is 180º.

The drilling test has been used to characterize stone hardness in depth and to evaluate stone treatments (in situ and in laboratory). The experience obtained has shown the value of the technique but several details are still open to study.

2- The mechanics of drilling and the chisel-edge effect

The DRMS is used with a conical or flat point twist drill bit with two flutes. This sort of drill bit has two main cutting edges, which do most of the cutting, and two lateral cutting edges which are engaged when the drill bit bends or wobbles during penetration. If the two main cutting edges are observed from the tip of the cone, it will be noticed that they do not meet at a point, lest an easily abraded tip would result. An edge is thus formed (called chisel edge) between the two cutters (figure 1) seen as a flat at the very tip of a bit that is observed from the side. This edge is the first part of the drill that engages the material and because it is mainly a non-cutting surface it works by cold-forming the material which is extruded away from the tip and pushed in the way of the cutting edges to be chipped off. Naturally this process is very hard on the drill bit tip and is the reason for the initial relatively high force that must be made to start and maintain a progressive penetration into a hard material. The rounding of the chisel edge by abrasion is also a main cause of the increase of the penetration force in an aging drill bit.

Figure 2 illustrates two typical DRMS graphs of drilling resistance versus drilling depth in the ARS ceramic reference material. Three main zones are evident: an indentation zone where the resistance grows rapidly and corresponds to the action of the chisel edge **(a)**; a conical-bore penetration zone of lower incline which corresponds to the engagement of the main cutting edges until the full bore is attained (this zone is non-existent for flat point bits) **(b)**; and a steady-state zone (considered the useful zone for characterization purposes) **(c)** which should theoretically have, in average, a nil incline but actually does not because of side rubbing of the drill bit, work wasted to do away with the cuttings and general edge wear.

As can be seen, the force at the end of the indentation zone represents a sizeable fraction of the total thrust needed for drilling. This fact is a disadvantage in itself because of the limited force range of the equipment and because any presentation of results in relative terms may be flawed by this large additive initial resistance. But there is also a purely physical reason to want to do away with the chisel edge effect: because of it any complete model of the mechanics of drilling have to consider two different kinds of cutting- an oblique model for the cutting edges and an orthogonal or indentation model for the chisel edge [3]. So, the DRMS drill measures the result of two related but different phenomena and when abrasion heightens the resistance to penetration both phenomena will result in different rates of increase and, potentially, further comparability problems.

3- Doing away with the chisel-edge effect

The chisel edge effect is a major concern in the machining of metal. Not only does it cause vibration and early wear of the drill bits but the wander of the drill tip over the surface before the first penetration causes positional errors that are often unacceptable. These problems are often dealt with by means of pilot holes: when drilling with a, say, 6mm bit, a first hole is made with a 2 or 3 mm bit, and then the full bore is drilled along the pilot hole. The rationale for this procedure is as follows: the smaller the drill bit, the smaller the size of the chisel edge and the lower the first penetration force. Also a bit of lower diameter is cheaper to replace. When the full bore drill bit engages over a pilot hole, the chisel edge effect does not occur and consequently the penetration resistance is much lower, the abrasion is also lower and the vibration is minimized because the drilling is now guided by the pilot-hole (figure 3).

We now propose that the same method be applied to the DRMS drill and will discuss the basic results.

We used the new technique exclusively in the laboratory, where the test items may be clamped to the drill thus ensuring that both holes are concentric. However the same method could be used in the field as long as a sufficiently rigid platform is used to support the drill. We aimed at making our results as thoroughly reproducible by other researchers as possible and so we used as test sample, for the purposes of this paper, a tile of the ARS reference material and as main bit a 5mm flat point diamond drill supplied by the DRMS manufacturer. The pilot hole was bored with a 3mm Tivoly alloy drill bit intended for ceramic materials.

In figure 4 we compare the graphs obtained from a hole directly drilled with the 5mm diamond bit and with the same co-axially over a previous 3mm pilot hole. As is readily seen, the average force measured for the second hole is much lower. The amount by which the penetration force is lowered includes the chisel edge effect and the work that the diamond bit would consume to remove the material already taken by the 3mm bit.

Not only the penetration force is lower but the absolute increase in force during the steady state penetration is also smaller and the random force oscillation (noise) is decreased. Table 1 compares the relevant data for both holes in the steady-state region between a penetration of 1mm and of 10 mm. To measure the random force oscillation, the force measurements were linearly regressed over the 1-10mm range and the standard deviation of the error residuals was computed.

It should be stressed again that when drilling over pilot holes the phenomena can be described through a simpler model solely based on the mechanics of oblique cutting and although the abrasion of the drill bit tip is never uniform (as can easily be ascertained by observing the edges of an aged bit under magnification) the results of wear are more easily accounted for. Erstwhile we could expect increases, at different rates, in both the indentation force and the cutting force. These increases derive from different phenomena that may potentially have different relative intensities for different stones. With the hole-over-hole method only the dulling of the cutting edges remains as main result of drill bit wear.

4- Improving the removal of dust

Another interesting side gain obtainable from this method is that, if the pilot hole is made to extend through the width of the test sample, the stone dust can be instantly removed during the test run by blowing compressed air through the pilot hole, thus eliminating the danger of packing and reducing wear by cooling the bit tip and decreasing corner rubbing.

The using of compressed air does not actually depend of a pilot hole but whenever it is used on a direct hole (in which case we call it back-blowing of air) the drill must be enclosed in a dust protector and the operators must wear masks. A quite spectacular result of the blowing of air is exemplified by the graph in figure 5, corresponding to a 3mm direct hole in which the air was turned on at 12mm penetration depth, after strong packing occurred. As can be seen, the dust was quickly blown out and the force fell down to the values measured at about 6mm penetration depth, whence the drilling proceeded normally. This graph was made merely to illustrate our point because when air is used, it must forcibly be used from the very beginning of the penetration with a definite air pressure and fixed position of the air blower, so as to obtain reproducible results.

When back-blowing of air is methodically used, it is observed that the thrust is consistently lower than in a drilling operation without air and that the resistance increases less with depth, presumably because no packing whatsoever occurs and the work needed to remove the dust along the flutes is now supplied by the compressed air. Since the removal of dust is parasitic towards the purpose of the test and often causes erratic thrust variations, the consequences of air-blowing are very welcomed. Yet, a full proposal as to its applicability needs a series of parametric tests aimed at defining the air velocity when it impacts the drill bit and these have not yet been made.

5- Increasing the range of the DRMS equipment

Tests are usually done by boring holes of 5mm diameter. Since the DRMS drill has a protection at 100N, harder rocks cannot be tested. Also very abrasive stones may destroy drill bits at shallow penetration depths resulting in the inordinate increase in force that will automatically halt the test before the desired depth is attained. But the 5mm holes may be feasible over 2 or 3mm pilot holes, thus increasing the useful range of the DRMS drill. And the pilot holes, not being the subject of measuring, do neither need be done with the DRMS drill, nor with one bit only. Whenever the smaller bit is abraded, it may be removed and sharpened to continue with the drilling, or replaced by a new one. After a number of such operations a pilot hole may be obtained to the desired depth and a measuring run then made with a 5mm drill bit. Also, a column drill may be used to bore the pilot-hole as long as an adequate centring system assures that the test item may then be co-axially mounted in the DMRS equipment for the test run.

It should be noted that, once established a reproducible method, the blowing of air may also be used to decrease the maximum thrust. In fact, those cases where the full bore was attained but subsequently the 100N limit brought the test run to an end because of packing, may now be tacked solely by the use of compressed air.

6- Some final remarks

We have shown that boring over a previous pilot hole with the DRMS drill results in lower thrust and less random force variation in measurements made in the ARS reference material with a flat diamond bit. We found that the blowing of air during the test run also contributes to the same purpose and feel that a standard method based on pilot holes and the through-blowing of air would decrease or eliminate known factors of dispersion and definitely result in a better reproducibility of any DRMS tests. Figure 6 backs this statement by comparing the results of two test runs on Carrara marble: **A** was a direct 5mm hole drilled with a flat diamond-tip bit; **B** was drilled with the same bit but over a blind 3mm pilot hole, with back blowing of air during the test run. Table 2 compares the relevant data and with it we shall rest our case.

We did not work with torque graphs (our version of the DRMS drill does not yet have this option) but given the losses by friction that characterize the chisel-edge effect and the torque fluctuations induced by packing, it is predictable that the gains in terms of stability (both in any single test and in the long run, throughout the useful life of any diamond drill bit) will prove to be considerable.

This paper merely presents a new method. Parametric tests are needed to ascertain whether it represents a definite improvement in all cases and for any type of stone. These are hampered by the fact that although 5mm drill bits intended for the DRMS equipment are readily available, the 3mm drill bits for the pilot-holes must be obtained from the market of construction equipment. Those bits presently available for stone are intended for impact boring and little suited for purely rotational work. In non-abrasive stones, drill bits intended for steel are perfectly satisfactory. In other cases the pilot-hole may be made at higher trust forces in a column drill, as long as the positioning system assures that a co-axial hole may later be drilled with the DRMS equipment. Yet, even in this case where there is no upper limit to trust or lower limit to the rate of feed, impact boring is excluded, so as to obtain a clean pilot-hole. The success of the method as we propose it depends on the possibility of boring pilot holes that will not introduce new parameters of uncertainty and so drill bits are needed that may be used to drill them in any stone at any laboratory in a reproducible manner ●

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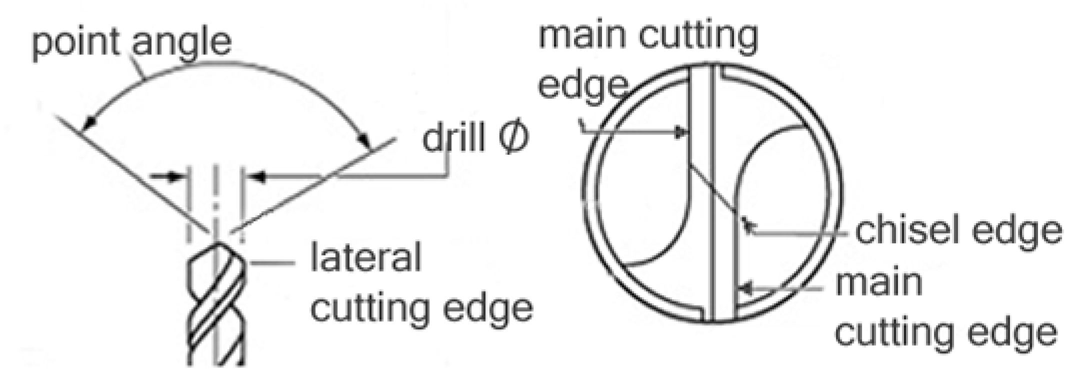

Figure 1 - Main edges in a simplified conical point drill bit

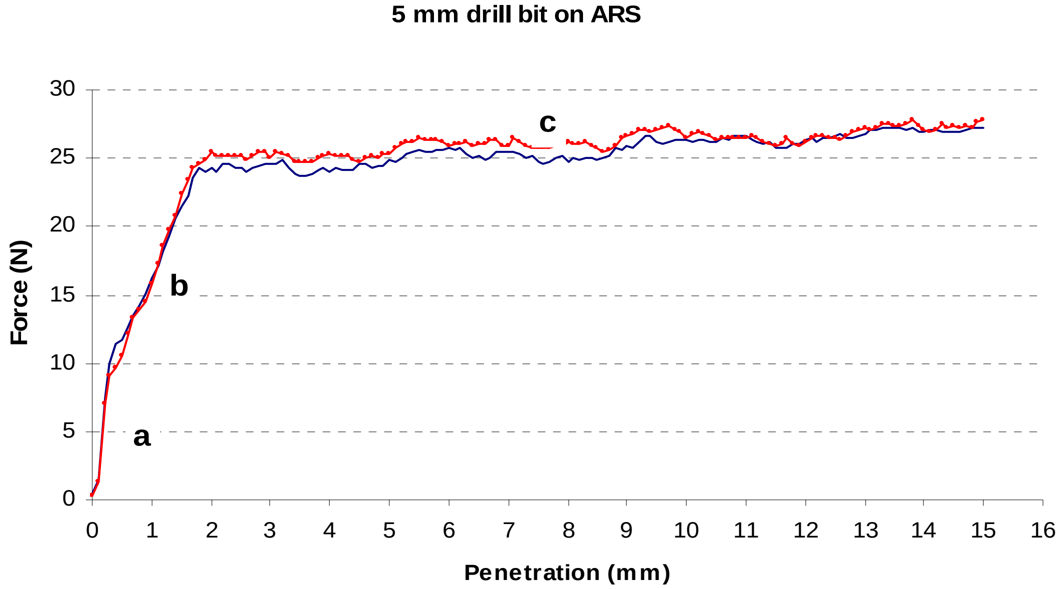

Figure 2 - Typical force vs. depth DRMS graphs made with a conical point drill bit

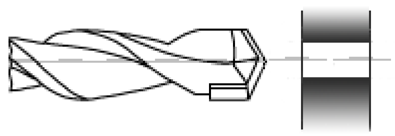

Figure 3 - Drilling over a co-axial pilot hole with a conical point drill bit

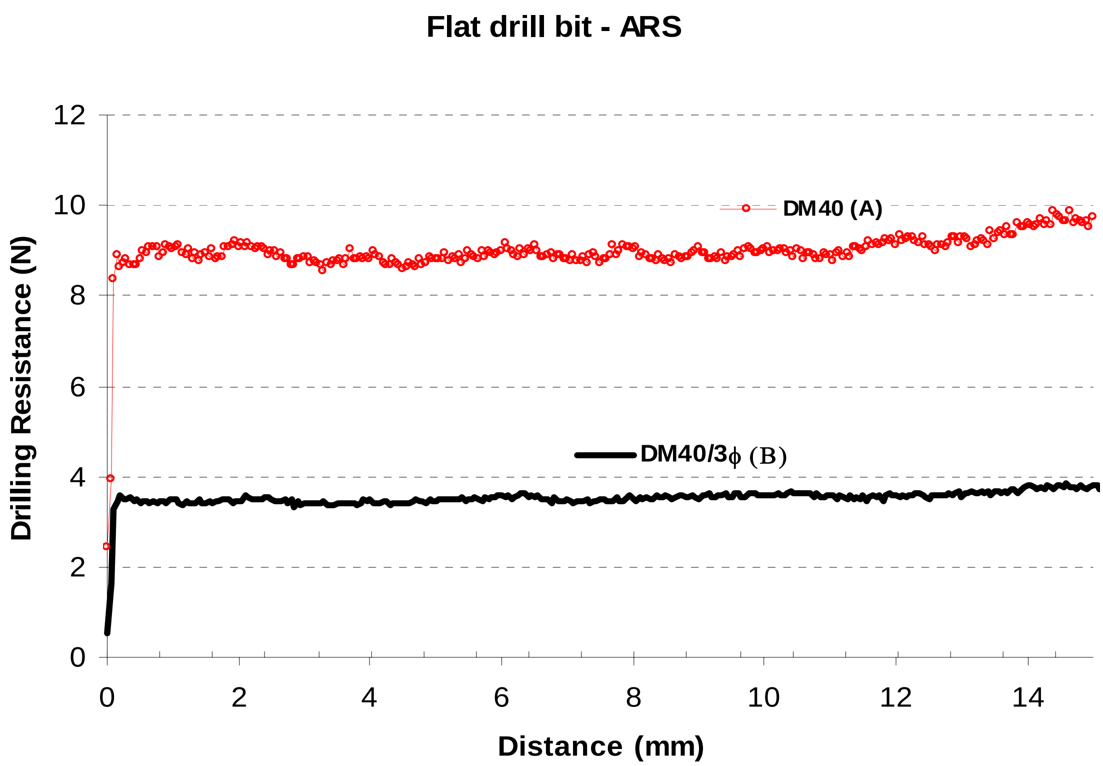

Figure 4- Graphical comparison of two 5mm DRMS holes: (**A**) by direct drilling (*DM40*); and (**B**) by drilling over a previous 3mm pilot hole (*DM40/3Ø*) on **ARS**

Measurements 1-10mm	**drill hole Ø5mm**	**drill hole Ø5mm over 3mm pilot hole**
-Average force	8.7 N	3.5 N
-Max/minimum force	9.5/ 8.1 N	3.7/ 3.3 N
-Std deviation of errors relative to linear regression	0.3N	0.1N

Table 1 - Numerical comparison of relevant data for a 5mm DRMS hole on **ARS** and the same over a previous 3mm pilot hole.

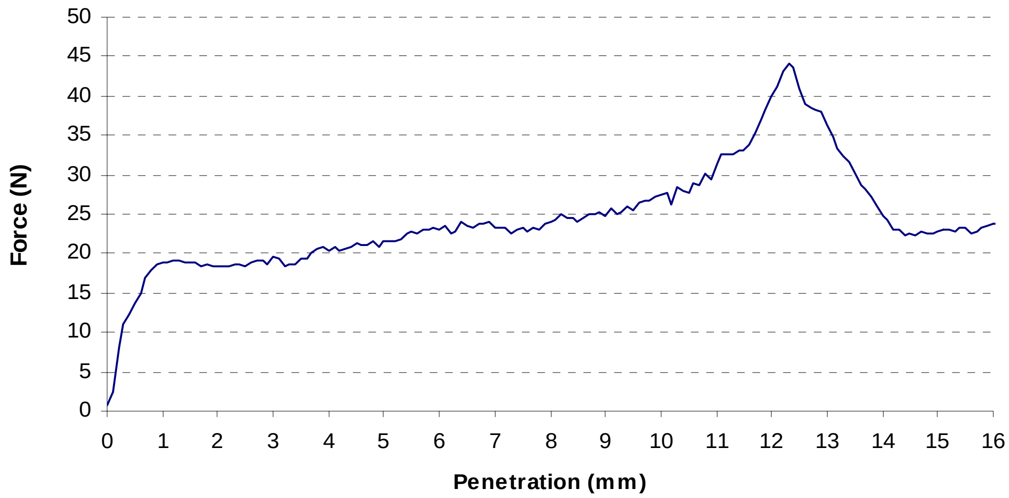

Figure 5 - Effect on packing of the blowing of compressed air- air connected at 12mm

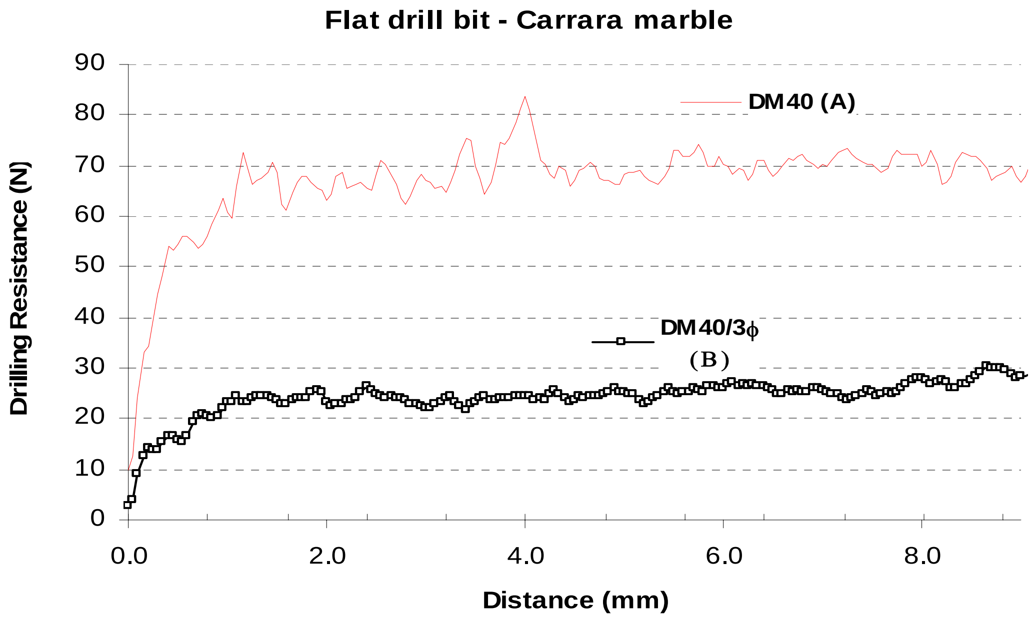

Figure 6- Comparison of two 5mm DRMS holes: (**A**) by direct drilling (*DM40*); and (**B**) by drilling with air over a previous 3mm pilot hole (*DM40/3Ø*) on **Carrara marble**

Measurements 1-9mm	drill hole Ø5mm	drill hole Ø5mm over 3mm pilot hole
-Average force	69.3 N	25.1 N
-Max/minimum force	83.7/ 59.7 N	30.3/ 21.8 N
-Std deviation of errors relative to linear regression	8.0N	2.7N

Table 2 - Numerical comparison of relevant data for a 5mm DRMS hole on **Carrara Marble** and the same over a previous 3mm pilot hole with back blowing of air.