Getting the Best Out of Nano-Dies for Cable Manufacturers

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Using Nano-Dies, the cable manufacturer can make some thoughtful process adjustments leading to significant improvements in the quality of the conductor body, raw material utilization and/or process speed.

A new product may be a seamless development of an old product. Or it might be a breakthrough technology inviting reconsideration of many things in the light of new possibilities. Nano-Dies from **Nano-Diamond America, Inc.**, are both of these things.

First, the techniques of Chemical Vapor Deposition (CVD), in which hard coatings may be applied to a substrate, is not new. What is new is the ability to create nanocrystalline diamond coatings of around 50 nanometer structure, strongly adhered to an inexpensive tungsten-carbide base material. Many industrial applications of this new technology are being developed concurrently, but the one which has found almost immediate widespread application is in the cable industry, for compacting and stranding applications. The product developed for this purpose goes under the name Nano-Dies.

The reasons for the early success of this new product in cable compacting applications are very clear. Cable compacting requires the use of very large dies. The advantages of using diamond tooling where possible in this application are well known, but it remains impossible or economically absurd to attempt to manufacture traditional polycrystalline diamond (PCD) blanks in sufficiently large sizes.

A PCD blank is essentially a solid mass of diamond particles forced together under extremely high pressures and held together by various bonding materials. It follows that, every time you double the diameter and thickness of a cylindrical PCD blank in order to double the achievable bore diameter, the amount of diamond material in the blank increases by a factor of eight and the price of the die goes up accordingly.

Furthermore, the amount of time and effort required to manufacture a perfect die profile in a large PCD blank is very large and very expensive.

PCD dies may be purchased (at enormous cost) up to a bore diameter of around 37.0 mm. Typically, only the largest cable manufacturers would use these large PCD dies at prices far in excess of US$25,000 per die.

By contrast, Nano-Dies may be readily manufactured up to a bore diameter of 60.0 mm. The nanocrystalline diamond surface is created inexpensively, during manufacture of the die. Standard delivery time is around four weeks. Comparing at the maximum possible PCD bore diameter, the price of a 37.0 mm diameter Nano-Die is US$2467. At 48.0 mm diameter, the Nano-Die price has risen moderately to just over US$3000.

In order to obtain the best performance from Nano-Dies in cable compacting, it is necessary to understand the basic characteristics of Nano-Dies, compared with the characteristics of PCD dies.

Friction

Nano-Dies have extremely low friction. **Figure 1** shows a fine-grain PCD surface (5 micron structure) and a Nano-Die surface (approximately 50 nanometer structure), each magnified by the same factor in a scanning electron microscope. It is clear that the Nano-Die surface is far smoother. There is no die surface that we know of that yields a better coefficient of friction than a Nano-Die.

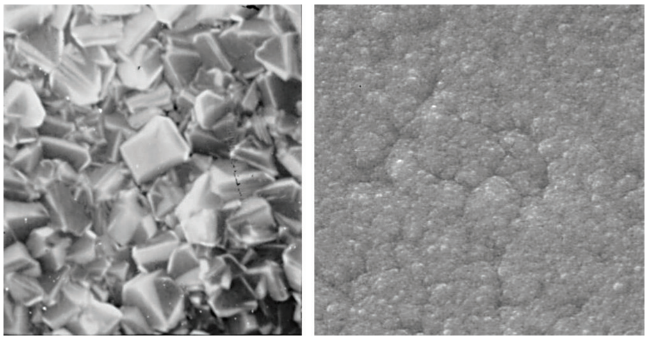

Fig. 1 — Contrasting the difference between the surface of a PCD die (left) and a Nano-Die (right) at 4000x magnification.

Hardness

The Nano-Die surface is all diamond and surface structure is uni-directional. The diamond particles stand like soldiers in formation. The workpiece sees diamond in the hardest known configuration of 1,1,1. The result is four to five times harder than a PCD surface.

The PCD die contains soft filler materials such as cobalt, which are used to hold the mass of PCD together. The particles are permitted to lie in any orientation and any direction.

Failure Mode

A nanocrystalline diamond surface continues as good as new at +0 bore diameter until the tungsten-carbide substrate develops metal fatigue and is no longer capable of supporting the diamond layer. At that time, a small crack develops in the nanocrystalline diamond surface and a scratch may become visible on the surface of the conductor body. The die should be replaced with a new Nano-Die at this point. The old die can be discarded.

By comparison, the failure mode of PCD dies is well known. The surface quality deteriorates, requiring the die to be polished or recut to a larger size. This is relatively difficult, time consuming and economically unattractive for large PCD dies.

Die Lifetime

For Nano-Dies used in cable compacting applications, 800 km of cable compacted is a general rule of thumb.

Bore Diameter & Surface Quality Over Time

It is well known that the quality of a PCD die deteriorates over time due to two related factors. First, the relatively soft filler materials wear away, exposing the jagged edges of the diamond particles, which increases surface friction. As this process continues, the workpiece begins to "pull out" bits of diamond material from the PCD material and this is what causes the bore diameter to increase (see **Figure 2a**).

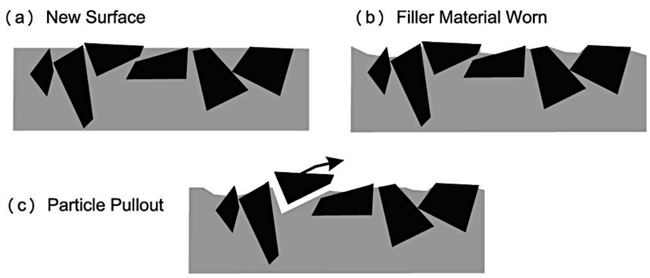

Fig. 2a — Schematic of PCD degradation.

By comparison, a Nano-Die holds a +0 tolerance during its entire life. This is due to the extreme hardness of the nanocrystalline diamond surface.

Here is the point that is most counter-intuitive about Nano-Dies—the Nano-Die surface quality actually improves over time. **Figure 2b** indicates the way in which the tops of the highly structured nanocrystalline particles may be flattened over time due to the action of the workpiece, causing unmeasurably small increase to bore diameter, but causing the surface quality to become better than when the die was new.

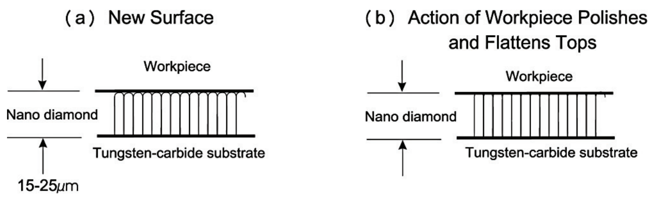

Fig. 2b — Nano-Die surface improvement.

Die Service

PCD dies require regular polishing and recutting service in order to keep them in operation. Nano-Dies require no repolishing or die service throughout their lifetime. They are trouble-free. Recutting of a Nano-Die is not even seriously considered, given the low cost of replacement.

Long Run vs. Short Run

Due to their excellent price to performance ratio, Nano-Dies are highly attractive for short-run production, and just as easily as for long-run production.

Nano-Die Usage Considerations

We are accustomed to thinking of the value of dies in terms of price/performance. It is an easy comparison to make. A die costs X dollars and delivers Y km of cable compacted. Nano-Dies do very well in any such comparison with tungsten-carbide dies or with PCD dies.

But here are some far more powerful ways to look at the real performance of dies in cable compacting:

1. Quality of the Conductor Body: Friction is the enemy of most things in cable compacting. We tend to think of compacting as a light and easy finishing process, but actually it is an extremely difficult process in which a cone of individual wires are brought into the compacting die at an angle of up to 30°, which greatly increases the contact length of the wires on the die surface. Hence friction is immediately increased on the wires forming the outer layer. Then the wires in the outer layer are significantly deformed, beginning at the line of contact with the compacting die. In a drawing process, the stresses and deformations are uniform around the full 360° of the cross section, but in compacting, we put flat surfaces on the cross-section, creating the classic "trapezoidal" cross sectional shape (see **Figure 3**). If the friction forces are appreciable, this extreme deformation causes damage which extends deep below the surface of the conductor, due to the additional frictional shear forces. The damage to the metal is done internally at the microscopic level. The scientific name for this damage is called crystal dislocation. The result is work hardening (familiar) and increase in electrical resistance or reduced electrical conductivity (not so familiar).

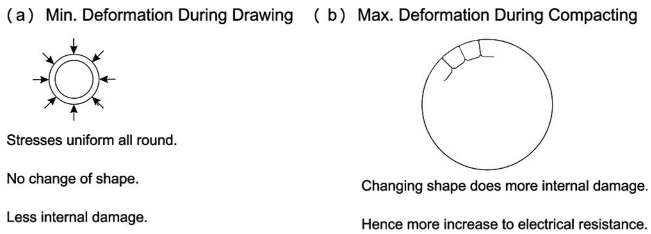

Fig. 3 — Deformation during compacting.

So the first benefit of using Nano-Dies is apparent. Lower friction means less internal damage to conductors, which means better electrical conductivity or lower electrical resistance in the finished conductor body. As the whole purpose of the conductor body is to carry large electrical currents without overheating, this is a very good thing.

2. Raw Material Utilization: It is possible, and many cable manufacturers consider it to be highly desirable, to develop step one, above, in order to make significant improvements in raw material utilization.

The most expensive component of a cable is the conductor body. The traditional test of DC electrical resistance per km is a remarkably good guide to the cable's ability to handle the required electrical load without excessive temperature rise.

Using Nano-Dies, the electrical resistance of the con-

Tip:

If you are using Nano-Dies to achieve optimum raw material utilization, avoid over-compaction. The savings due to raw material utilization will far outweigh any possible savings due to a smaller outside diameter of the conductor body.

ductor body is reduced in step one, so we now have the ability to make slight adjustments to the design of the cable. By very slightly reducing the diameters of the individual conductors, the electrical resistance of the conductor body can be brought back to where it was originally (still fully compliant), but raw material utilization will be greatly improved.

Users of Nano-Dies typically report significant improvements in raw material utilization in this step. For aluminum cables, 2.4% reduction in total aluminum usage has been reported (compared with the best result previously achieved using PCD dies).

For copper cable, up to 1.8% improvement is reported, but 1% improvement is more common. Of course, 1% copper savings is an enormous improvement in dollar terms. Cable manufacturers who exchange their tungsten-carbide dies for Nano-Dies report improvements in excess of 2% when compacting copper.

3. Speed of Manufacture: If we start again at step one, the electrical resistance of the conductor body has been reduced by using low-friction Nano-Dies of the same diameters as the previous dies, regardless of the type of the previous dies. But this is not the only good thing that happens. There may be a very obvious reduction in process temperature (40°C instead of 46°C in a well-recorded example comparing a final Nano-Die with a final PCD die of the same bore diameter).

This is very easy to measure with an inexpensive infrared thermometer. If higher production speed is the objective, Nano-Dies make it possible to increase the speed of a stranding machine by a surprising amount.

For example, rigid strander fitted with Nano-Dies has been reported to run perfectly at 60 mpm. Again, the lower friction of Nano-Dies is the obvious reason. Temperature rise is caused by friction and by speed. Friction here is lower, so speed may be increased until the original process temperature is reached. But now the machine is running much faster.

4. Process Improvement: The important subject of process improvement is not strictly the business of the die maker. Two questions the die maker is frequently asked are, "What final die diameters should I specify when ordering Nano-Dies?" and "How much should I reduce the diameters of individual conductors if I am looking for better raw material utilization?" The die maker alone cannot answer either of these questions with absolute confidence.

In step one, above, you may proceed with dies of the same diameters as your previous PCD or TC dies, in order to demonstrate an improvement to the quality of the conductor body. The question is, what do you do next? The die maker alone cannot answer that question. What the die maker can say is:

- Slightly reducing the diameters of individual conductors has a very predictable effect on electrical resistance (up) and on total raw material usage (down). So you need to make sure you have made an improvement to electrical resistance before you lighten conductors. Careful measurements of electrical resistance are made much easier by readily available test equipment designed especially for this purpose. Typically, such equipment pays for itself in a few weeks or months at the most.
- If you are using Nano-Dies of the same diameters as the dies you were previously using, the conductor body will now be less tightly compacted than before, as less metal is being compacted after the conductor diameters have been slightly reduced.
- A lower value of compaction itself causes less damage to the conductor body, leading to the strong possibility of still further electrical resistance reduction.
- The second and third points above each suggest that the diameter of the final compacting die may be slightly reduced if desired to restore the original compacting ratio, leading to savings in all the materials (armoring, insulation etc.) that go outside the conductor body.

Many factors outside the control of the die maker will affect the final performance of a compacting process. To list a few of the main ones, speed, angle of the cone of wires entering the compacting die, compacting ratio and lubricant (if used), all have a powerful effect.

Many cable manufacturers have more than sufficient process knowledge and experience (more than their die maker in most cases), enabling them to manage all of their own process improvement without reference to any outside service.

For those who seek help, there are several levels of assistance available. First, the manufacturer of Nano-Dies is happy to provide an initial free-of-charge consulting service. Second, there are a few excellent services available and anyone is welcome to ask us about particular services with expertise in using Nano-Dies.

To receive additional information and technical specifications on Nano-Dies, contact the author at Nano-Diamond America, Inc., or visit the company's website listed below.
www.nan-die.com **WCTI**

Company Profile:

Nano-Diamond America, Inc. *supplies the wire and cable industry with innovative and long-lasting tooling for industrial applications. Nanocrystalline diamond composites are used to achieve significant productivity improvements over traditional diamond tooling. Nano-Diamond America's mission is simple—to make these high-performance and very attractively priced products readily available in world markets. The major market segments in which Nano-Diamond America, Inc. operates include the wire industry, the energy cable industry and the tube manufacturing industry. The company's main product is Nano-Dies. Nano-Dies are hard at work in every industrial region of the world, conserving raw material, providing better surface finish, extending tooling life and reducing tooling costs.* ***www.nano-die.com***