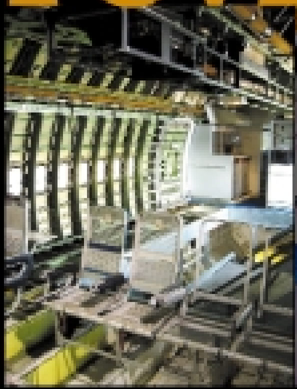
recast revisited

(courtesy — Mecartex)



(courtesy — Boeing)

(courtesy — General Electric)

By E. Bud Guitrau

introduction

The ability to produce tooling or parts in difficult-to-machine alloys that can have smooth finishes, complicated geometry and close tolerances, has long been an attractive aspect of EDM. So attractive, that when these capabilities became known to manufacturers outside of tool, die and moldwork, the rush to have everything EDMed was great. Unfortunately, general knowledge of the EDMed surface and the level of generator sophistication and operator training wasn't as great. Consequently, many critical and non-critical parts were unknowingly being EDMed improperly.

in the early days

Moldwork was the sinker's first and greatest claim to fame and mold steels readily accepted the EDM process with few problems, even in the corrosive environment of aluminum die casting. As other industries learned of EDM's capabilities, they too sent their parts out to be EDMed or they bought their own equipment. Many, many parts were soon being EDMed, but over time, certain materials in certain applications began to show disturbing signs of imminent failure or had failed prematurely. High-torque, oil drilling components would break, forging and heading dies developed cracks, and chipped elements of turbo machinery showed signs of surface and stress microcracking during preventive maintenance inspections and destructive testing. Fortunately, there are no known EDM-related incidences or injuries, but a bright caution light came on and the manufacturing engineering world began to heed it.

Cyclic and destructive testing determined that stress risers in the form of microcracks and other surface anomalies were present in certain materials that had been EDM'ed. Continued testing proved that EDM was often a common denominator in the propagation of stress cracking, and in some materials, the surface hardness could be found to be one or two points higher or lower than an adjacent non-EDMed surface. It became obvious that some semblance of EDM management be created.

EDM "standards"

Soon, several different versions of EDM standards began appearing. Most were internal standards and testing procedures that had been written by large companies for processing their own parts. Unfortunately, most findings and standard-writing were composed independent of others, as they were often competitors. Each set guidelines, but with little coordination or continuity among them. There have been instances where one standard would allow EDM to be used on a certain aircraft part, and another standard would prohibit it. The only thing standard about these standards was they were not.

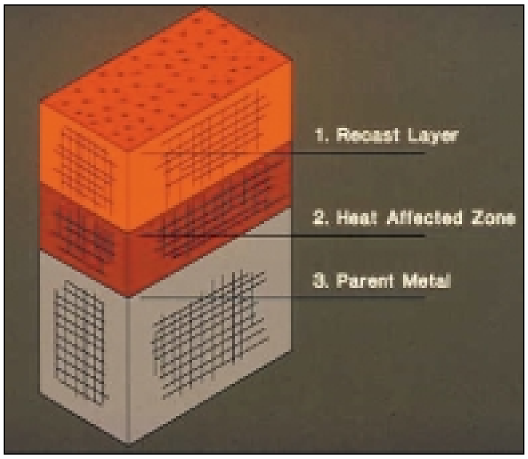
Even after many years of EDM development and improvement, some of these standards still prohibit EDM entirely, while others would allow EDM only if certain second and even third post-processing operations were performed on the EDMed surface. The subsequent increases in labor and post-processing costs made many previously cost-effective EDM operations too expensive. It also prompted many newly-cautious engineers to specify the conventional machining of aircraft parts that had previously been EDMed — even simple EDM jobs like keyways went back to being broached. Many jobs were pulled from EDM cells and job shops and manufacturing route sheets were rewritten, almost always limiting or restricting the EDM process, and often requiring post-processing to remove the EDMed surface.

Post-processing methods for EDM can range from hand and machine polishing, abrasive flow machining (AFM), shot-peening, grinding, heat treating and electro-chemical machining (ECM). All of these processes are used in varying degrees to reduce, remove or otherwise eliminate what the engineering world had discovered and was so logically concerned about — the thin layer of metal remaining on the surface of an EDMed part — the recast layer.

the recast layer

So what is the EDM recast layer and why the concerns?

First the description — With the initial strike of the EDM spark, current is generated and the spark begins to vaporize a small crater, reducing this area of the workpiece material to a gas. As the EDMed crater gets larger, its increasing surface area begins to sink heat away from the spark gap until vaporization temperatures can no longer be sustained, and melting begins. This forms a molten globule and as melting continues, this globule grows in size until it eventually attains enough mass to break away from the heat source and solidify within the dielectric to be flushed away.



If this melting process could continue without interruption, there would be much less thermal and chemical influence upon the cut surface, but an interval of off-time is required to flush away the eroded material, and to allow reionization of the damaged dielectric. During the off-time, when the current is switched off, melting ceases instantly and all of the molten material not large enough to break away in the form of a sphere, is drawn back by surface tension, and resolidifies back onto the cooler parent material. This thin layer of resolidified material is called “recast” or “remelt” and can be quite different in both its physical and chemical conditions than that of the parent material. It is also called the “white layer” for the way it often appears in a section view under magnification.

Now the concerns — This changed layer of recast material left on the cut surface can have physical properties that are contrary to the part’s engineered purpose. The actual EDMed surface could now be too hard or too soft, too brittle or too ductile, and simply too unpredictable. Before we examine the complex *chemical* influences on the EDMed surface, let’s make the *thermal* aspect of EDM recast clear by using a very simplistic analogy.

fire & ice

Remove an ice cube from the freezer and watch as you swipe your thumb across the top of it. The heat and pressure of your thumb will briefly melt a thin layer of water that will quickly refreeze after it passes. Although the ice cube’s chemistry didn’t change — it remains H^2O — this thin glaze of quickly-refrozen ice will have a different crystalline structure than the body of the ice cube that froze slowly over several hours. Although the thermal effects of your thumb on an ice cube are much less than that of a plasma-hot electrical arc discharging onto a metallic workpiece, the glaze on the ice cube provides a simplistic, yet acceptable explanation of the thermal effects of EDM on a workpiece. While this comparative explanation of ice and metal is simplistic, their real-world differences are not.

it’s not that simple

It’s too bad that EDM recast isn’t as simple as the example of the glazed ice cube. Not much occurred in the case of the ice cube — ice was briefly melted and refrozen, changing the *structure* of this thin layer but *not its chemistry* — the glaze on the surface of the ice cube is still frozen water — H^2O.

However, the thin layer of recast material on a metallic, EDMed surface is not only *thermally* changed by rapid melting and refreezing, it is also *chemically* changed, by the release of parent material and the absorbsion of dissimilar elements that have been freed from the electrode, the workpiece and the dielectric by the elevated temperatures of the plasma-hot spark.

the electrodes

Determining the elements that EDM electrodes contain is simple, as there are only a few common electrode materials being used. In the case of a sinker, the most commonly used electrode materials are, in order, straight graphite, copper infiltrated graphite, copper, and copper tungsten and tungsten. The major elements released from this group would be carbon, copper and tungsten. Copper and brass tubing are used for EDM hole drilling, and will release copper and zinc.

Wire electrodes are also simple, with most EDM wires being in the copper-family, although a very small percentage of molybdenum and tungsten wires are also used. There are also low-carbon steel-core EDM wires that are for fine-diameter and/or high-tensile strength applications. The chemistry of the steel core of these wires is not included here, only its high-zinc brass coating, because if cutting is being done with the steel core, then the wire-runoff speed is too slow for the workpiece thickness.

Wire EDM electrodes can contain copper, zinc, molybdenum, tungsten and in some wires, trace amounts of aluminum and magnesium. So far this isn’t too complicated, but we’ve only just begun with a few electrode materials.

the workpiece

Complications increase considerably with the addition of the elements of the workpiece. Considering the enormous number of workpiece materials and alloys that can be EDM’ed, then at least in theory, nearly every element might be encountered and released. Let’s look at a few.

On the tooling side, let’s consider any common grade of tool or alloy steel. Of course there will be lots of iron, but in no particular order, there can also be chromium, vanadium, manganese, molybdenum, carbon, cobalt, silicon, nickel, tantalum, sulfur and other elements present. For aircraft and aerospace jobs, titanium alloys can contain aluminum, vanadium, iron, molybdenum, and others. Aluminum can be alloyed with silicon, iron, copper, manganese, magnesium, zinc and others. All of these elements are released from the workpiece during EDMing and are added to all the other elements that are simultaneously being released from the vaporizing electrode and dielectric.

the dielectric

Here's where things really get complicated. We know that sinkers use oil and wire machines use deionized water. Both are dielectrics and support the EDM process, but their effects upon the EDMed surface are literally as different as oil and water, and will produce not only a completely different appearing surface finish, but will leave recast layers with entirely different chemical compositions.

DEIONIZED WATER — The water dielectric of a wire machine is very basic, comprised of only two parts hydrogen and one part oxygen — H^2O. During the discharge cycle, the plasma-hot spark will "crack" the water, separating the compound water into its elemental components — hydrogen and oxygen.

HYDROGEN — Inert in the EDM environment insofar as having any influence upon recast, but hydrogen is flammable and can contribute to a sooty discoloration, or produce "dirty-looking" wirecut surfaces, especially in the case of tall parts and/or poor flushing conditions.

There have been theories circulating for years that when wirecutting porous materials such as cellular metals, metallic foam, metal sponge or low-grade graphite, hydrogen gas can somehow accumulate in the pores and voids of the workpiece, and when ignited by the EDM spark, the trapped gas "explodes" and breaks the wire. Although wirebreaks do occur often in these applications, I am aware of no study or research that has examined or proven that mini-hydrogen explosions are responsible for wire breaks.

OXYGEN — By its very nature and namesake, is an oxidizer and combines readily with almost all known chemical elements, especially metals, and especially at elevated temperatures. With this being said, it stands to reason that almost all materials EDMed within a water dielectric, will have a cut surface that is slightly oxidized, especially after high current, roughing operations.

In certain non-ferrous materials such as aluminum and magnesium, this oxide layer is nonconductive and can prevent subsequent skim cutting. This condition is often experienced after aggressive rough-cutting and after EDM-drilling start-holes in a water dielectric "hole popper", where aggressive settings facilitate high-speed hole drilling, but often leave a non-conductive oxide layer that can prevent the entry wirecut. Before setting up for wirecutting, many users will "float" the next-size drill or reamer through the EDMed hole on a drill press or knee-mill, to remove the oxide layer and expose the conductive material beneath it.

It must also be noted that a heavily oxidized wirecut surface can affect other downstream processes such as plating, anodizing, painting, Teflon coating and joining.

This type of oxidation can have a slight softening effect on the surface hardness of ferrous alloys, especially after high-current, roughing passes in the older, DC generators, but the combination of sophisticated AC generators and improved techniques and execution, has reduced this and other recast-related issues to having very little measurable effect.

Slight traces of copper and zinc from the wire electrode can also be alloyed within the recast layer, although there is usually a higher incidence of copper, because the melting and boiling points of zinc are lower than copper and will be vaporized more quickly. This is not to be confused with the condition called, "brassing", when the combination of electrical continuity and water conditions can cause a dull brass buildup on the part's cut surface. This is not recast material, but a mild plating condition that does not penetrate the part and can be removed with a baking soda blasting. Heavier deposits can be removed with a fine glass-bead, but this can affect the accuracy of close-tolerance parts.

DIELECTRIC OIL — Most EDM oils are either a petroleum or synthetic hydrocarbon. In either case, the keyword here is *hydrocarbon*. A hydrocarbon is an organic compound consisting entirely of hydrogen and carbon. Other chemicals are present in EDM oils, but the primary constituent is the carbon-rich hydrocarbon base derived from petroleum, coal tar and organic plant resourses.

There are three groups of hydrocarbons; aromatic, napthenic and pariffinic, with most EDM and transformer oils being pariffinic for its good insulating qualities. Additionally, although unrelated to this study, pariffinics are chosen for EDM oils because they have excellent stability (resistance to oxidation), high pour point, higher viscosity index, higher flash points and low specific gravities — all desirable qualities of a good EDM dielectric.

Just as the heat from the discharge cracks the water, it also cracks the oil, releasing hydrogen that has little effect, but in the process, releases vast amounts of carbon and other elements. During off-time, when the current is switched off, the plasma bubble collapses and the carbon-rich oil quenches the molten surface. Depending upon the material's affinity for it, various amounts of carbon atoms are assimilated into the cooling molten metal, essentially producing a *carburization* process, changing the surface chemistry of the EDMed surface.

This affects ferrous alloys more than others and during off-time, carbon atoms are held in solution with iron, and the resulting recast layer is martensetic (and harder). During high-current roughing, several layers of micro- and tension-cracking can occur, but this is of no consequence, as long as this thermally-influenced layer is removed during subsequent sizing and finishing of the cavity.

a final note on dielectric

Earlier, we examined how many different elements can make up a given workpiece and be released during EDMing. In the case of a wire machine, the chemistry of these metallic ions are neutralized by the deionizing resin, but in a sinker that has no such device, these submicron elements remain suspended within the dielectric, and continually pass through the filters and gradually build in concentration along with the byproducts of the electrode and the dielectric. Over time and as these metallic elements grow in density, they gradually lower the resistivity of the oil and allow for a slightly quicker spark initiation. This is why we have often heard complaints that a fresh, new oil will cut slower than an older, more "seasoned" one.

From my own experience, I too have experienced this machining "slowdown" after replacing aging EDM oil. This was in a toolroom and everything was in small lots, so no actual time-study could be done for an actual then-and-now comparison, but as I recall, everything seemed to run at least 10% slower for several months. As frustrating as this was (including suspecting generator problems until I learned more), the parts had slightly better finishes and a cavity would run a tenth or two smaller (steel-safe).

The speed loss after a complete oil change is from the higher dielectric strength of the fresh oil, and the fact that the oil is simply clean, meaning *fresh*. High dielectric strength is required to prevent premature ignition and to allow quicker reionization and recovery. A new oil with a high dielectric strength, can "hold back" the spark better than a worn and depleted one, effectively allowing the generator to operate more precisely, while giving the control better control. Additionally, a fresh oil has no pre-existing build-up of metallic ions that lowers dielectric resistivity and contributes to premature initiation.

The .0001"-.0002" increase in material remaining after an oil change was because there were no metallic ions and semi-conductive chips within the spark gap, greatly reducing secondary discharge, preventing any uncontrolled and unwanted metal removal. Literally, a *cleaner* burn.

Of course, everyone wants to burn faster, but in this case, temporarily slower machining speed that produces quality parts is a much better alternative to faster, but "sooty" burns, deteriorating finishes, inaccurate dimensions, pitting and possibly arcing, all caused by a spent and depleted EDM oil. A fresh oil will almost always yield better quality parts, especially in marginal conditions with poor flushing.

The combination of the thermal damage and breakdown of the hydrocarbon chain, and the gradual build-up of metallic solids, contributes to the staining and darkening of the oil. Other than reduced part visibility, this has little influence on the machining process, but more on the final chemistry of the recast material. A darkening oil is a good indication to pay attention to its age and condition.

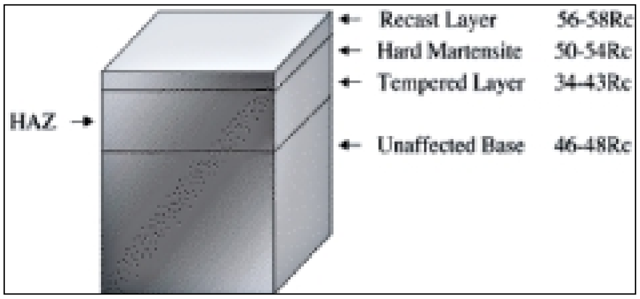
the heat affected zone

Immediately beneath the recast layer is an area called the "Heat Affected Zone" (or HAZ). This is an area that has been only partially affected by the elevated temperatures of the spark gap. Within this area, the metal did not approach temperatures high enough to actually melt, but it may have reached temperatures high enough to change its temper, reducing its hardness.

Depending upon the material and the temperatures reached, the HAZ can vary as much as ten points in hardness than the unaffected parent material. This is due to the hardening and tempering effect, caused by the elevated temperatures of the material near the spark gap.

A good example of this condition would be during the sustained, high-current roughing of a large, forging die made of H-13 that has been hardened and drawn to 48Rc.

In this example, the heat affected zone (immediately beneath the recast layer), can be .010" to even .020" thick, and is comprised of hard, untempered martensite, that phases into a softer, tempered region, before giving way to the 48Rc parent material. This heat



(courtesy — Accelent, Inc.)

affected zone is the normal result of sustained high current machining, and if properly executed, will be completely removed during the subsequent stepping and finishing operations.

For better control and to reduce the thickness of this layer, a dielectric chiller should be used. Not only to keep the workpiece and electrode cooler, but because a warm oil “cuts slow”, perhaps as much as 50% slower at 150°F than at room temperature. Also, parts will be more accurate when they are machined at or near room temperature.

RULE: If the dielectric oil is warm to the touch, it is too warm.

The thickness of the recast layer and the HAZ immediately below it, will depend upon the chemistry of the workpiece material, the ability of the material to conduct and transfer heat away from the machined area, along with the current density and frequencies used during machining.

Today, the heat affected zone is basically a non-issue in WEDM, because even during roughing, current density is localized in a very small area, and cutting submerged in chilled-water keeps the entire part cold and prevents heat from penetrating into the part. Just consider the thin sections of a solid-metal flexure, which can range from .010” to less than .002” depending upon the material, yet it still retains its flexibility after wirecutting, without becoming brittle or breaking.

Any effects of recast or HAZ would surely be revealed during the use of the device *above*. Another example would be in very small parts, such as the various watch mechanisms on the *bottom left* with a paper clip at the top for scale. (courtesy — Mecartex)

Historically, all diagrams demonstrating a section view of an EDMed material have had three distinctive bands (including my own). The top layer was recast, the second was the HAZ, and the bottom layer represented the unchanged body of parent material. Today, in a properly executed EDMed part, the formerly always-present heat affected zone is becoming practically non-existent depending upon the workpiece material, as test results will reveal.

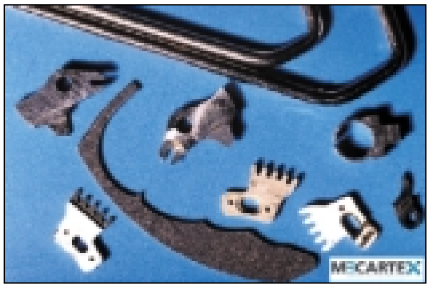
test results

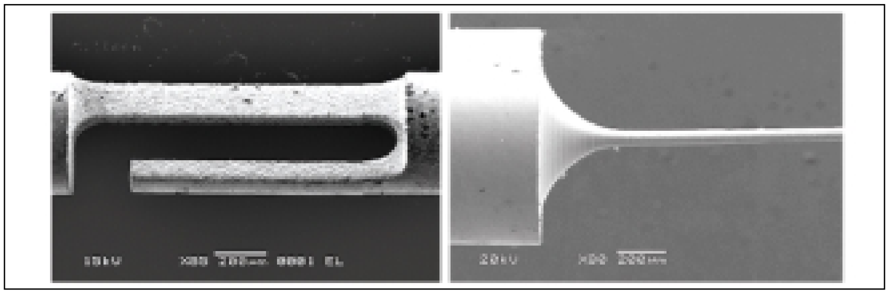
Photomicrographic evidence of the recast layer and the heat affected zone, along with cyclic and destructive testing of parts, continues to show that modern EDM technology can produce EDMed details that have minimal influence on the workpiece surface and structure. Important to all manufacturing, this is particularly important to structural parts, impact and edge-wear tools, and the myriad of materials that are used in the aircraft and aerospace industries.

The test results that follow were executed by a Nadcap accredited material testing laboratory on three common aerospace materials; titanium, stainless steel and aluminum. Part of a larger study, the following are samples of two and three-pass machining, a realistic degree of processing in today’s production environment.

Samples were wirecut with plain brass and coated wires for comparison. Although surface finishes were better with the coated wires, the difference in recast is almost immeasurable. In this particular group of samples, a heat affected zone of .0001” was detectible only in the titanium samples with either wire type, and there was no subsurface softening at a .0025” micro hardness depth in any material sample.

Positive results such as you are about to see, will continue to allow





(courtesy — National University of Singapore) design and manufacturing engineers to confidently specify EDM and WEDM for the speed, accuracy and cost-saving properties they seek, without needless concern for part integrity and safety. The minimal effect of recast, and the near-absence of a heat affected zone, demonstrates the degree of generator sophistication and the ability to produce safe and reliable parts economically and consistently for any industry.

Only three common alloys were reviewed here, but they were selected purposefully, to cross as broad a spectrum of materials and properties as possible. More are planned and will include all-important sinker studies too. All show strong promise that modern EDM can be used to economically produce almost any suited part and continue to explore the ever-shrinking, parts-world of medical devices, micro-electronics and micro-machining.

summary

Everyone must agree that EDM has come a long way since its primitive beginnings of driving DC generators through copper wire, or fabricating a dozen electrodes for a single detail while using negative polarity and capacitors. Unfortunately, most of the standards for EDM were written during this same period and are just as primitive. Obviously good for all of precision manufacturing, would be a re-examination of EDM's "kinder and gentler" surface influence, supported by its creative capability, along with the satisfaction of running long, unattended hours generating revenue.

Regardless of the type of machine, the dielectric, or the material's metallurgical composition, the recast layer is an inherent byproduct of the EDM process and is unavoidable. Although today's sophisticated new power supplies with high-speed switching, modified wave forms and improved generator technology now provide a very fine degree of control, resulting in minimal topical metallurgical influence, the thermal nature of the EDM process itself makes it impossible to eliminate recast entirely.

Although, once-upon-a-time, the elimination of the heat affected zone was also considered an impossibility, yet it's being done as you read this. Who knows... perhaps in the future, we'll have an EDM finish as benign and benevolent as a glazed ice cube.

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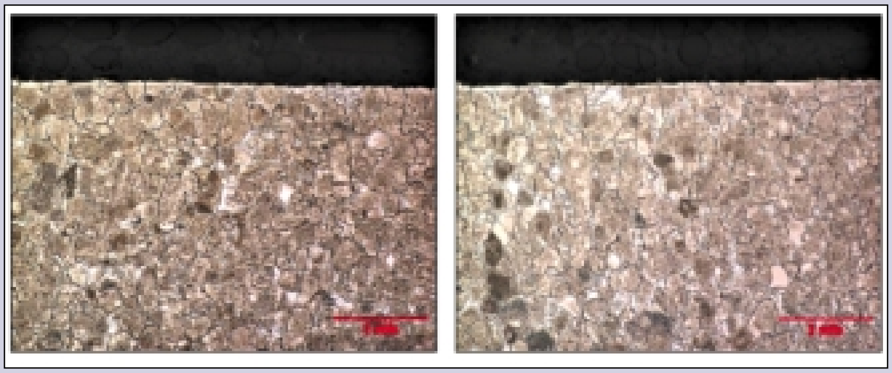
titanium

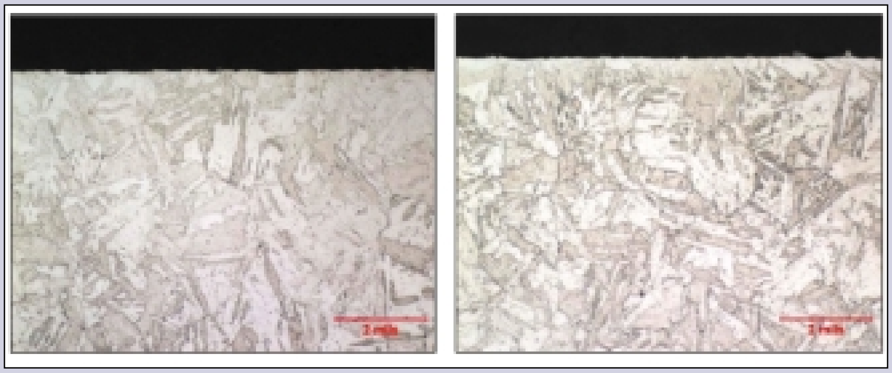
Al-4V / brass wire — 6Al-4V / coated wire



Max recast:	.0002"	Max recast:	.0002"
Avg recast:	.00005"	Avg recast:	.00004"
Recast cracks:	None	Recast cracks:	None
HAZ:	.0001"	HAZ:	.0001"

stainless steel

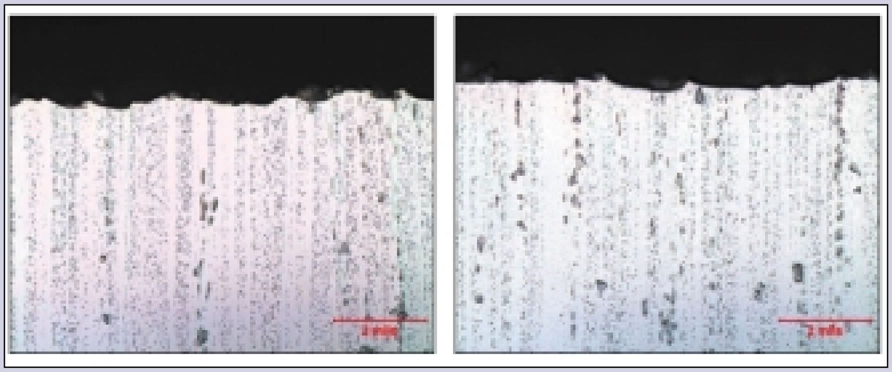
17-4PH / brass wire — 17-4PH / coated wire



Max recast:	.0002"	Max recast:	.0002"
Avg recast:	.00002"	Avg recast:	.00003"
Recast cracks:	None	Recast cracks:	None
HAZ:	None	HAZ:	None

aluminum

6061-T6 / brass wire — 6061-T6 / coated wire



Max recast:	.0004"	Max recast:	.0005"
Avg recast:	.00006"	Avg recast:	.00006"
Recast cracks:	None	Recast cracks:	None
HAZ:	None	HAZ:	None

All cutting tests were performed on a Makino SP43 wire EDM machine. Testing data and micrographs courtesy of Makino and IMR Laboratories, a NADCAP certified facility.