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Edge and Surface Conditioning for Improved Part Performance and Service Life

INTRODUCTION: When presented with edge and surface finishing problems, many manufacturers continue to reach for solutions that rely on out-of-date, time-consuming and labor-intensive methods. It is still not unusual to see precision parts and critical hardware being manually handled and edge and surface finishing operations being performed with abrasive hand tools, or manually controlled power tools that utilize coated abrasives or abrasive filaments. This situation often arises from insufficient planning and a lack of understanding what will be required to render the manufactured part or component acceptable for consumer use or end-user application. The authors discuss the importance of understanding mass finishing methods, not only as economical methods to automate finishing processes, but also as an important strategy for improving overall part functional performance and service life.

Prior to the early 1970s, there was little to no awareness of the relationship between part function and the process that created a piece part. Many areas of automotive power train manufacturing were starting to realize that component failure was causing increases in scrap and warranty costs even though the used metallurgy, fit, and form were specified and controlled properly. There was no unified understanding of the root cause of premature wear, leakage, noise, unusually high operating temperatures, and catastrophic failure, or even if they were related.

DEFINITIONS A conventionally produced surface (turned, milled, ground, EDM) is typically Gaussian in nature, that is, the peak and valley distribution is pretty much equal in height. This type of surface can be very unstable and unpredictable when wear and load bearing are considered. The images in Figure 1 demonstrate this type of surface. There are many ways to produce plateaued surfaces. They are varied in approach but all can control the surface peak characteristics separately for the valley characteristics. This is summarized in Figure 2, showing that the peak and valley distributions can be controlled to allow substantial bearing load capabilities (broad, flat areas) with well-defined lubrication, debris collecting valleys.

Engine Cylinder Bores: Honing cylinder bores produce an evenly distributed (Gaussian) surface of peaks and valleys. Lubrication (lube) retention is dependent on the valley portion of the surface, allowing even distribution over the entire swept area of the piston and rings. Contrary to that, the peak portion of the surface was not supporting the needs of other bore requirements, such as reducing friction, sealing to the piston ring, and reduction of wear. As extended warrantee life (now over 100,000 miles in diesel applications), emission requirements, and higher combustion temperatures evolved, the need for more control of the surfaces became evident. Plateau honing was first used as a final cylinder bore finishing technique in the 1970s. Later (1980's), the diesel industry was instrumental in incorporating this technique to extend engine life and improve the sealing

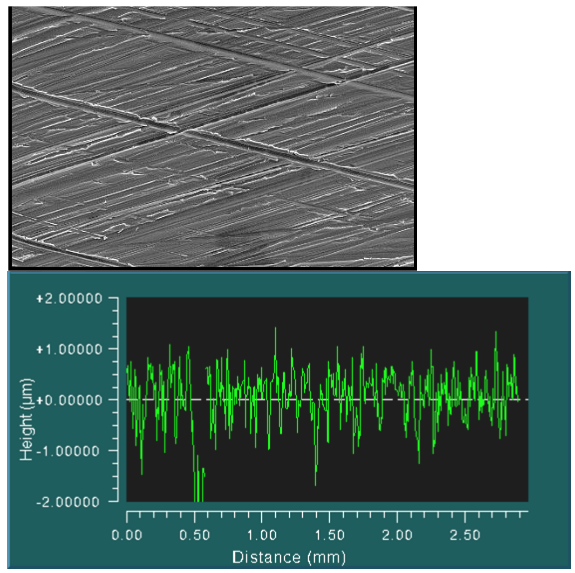

Figure 1: Typical positively skewed surface common to most grinding and machining operations. (Courtesy of Jack Clark, Surface Analytics, Ft Collins, CO.)

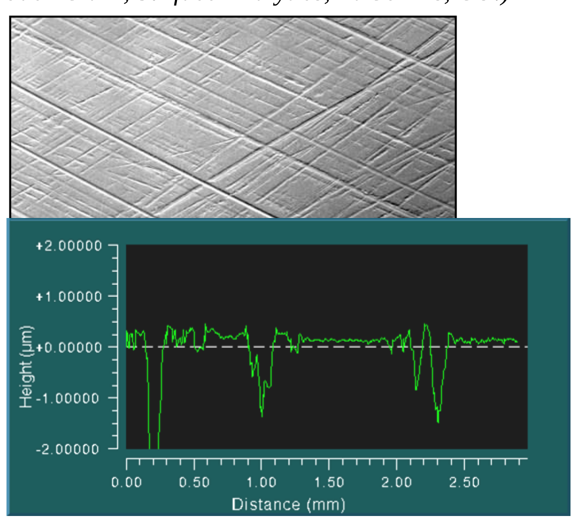

Figure 2: Plateaued surface as typical of surface conditioning produced by a variety of mass finishing methods. (Courtesy of Jack Clark, Surface Analytics, Ft Collins, CO.)

of the piston ring to the bore. Today, the gasoline engine manufacturers are finding that they must migrate to these bore conditioning practices to meet emission requirements and, again, extend predictable engine life.

The solution has been in respecifying bore materials and implementing new honing techniques. The old standard of cast iron was a material that did not support finely controlled machining processes. Consistently, there were issues with tears and folds in the surfaces, poor plateau, and frictional characteristics. Manufacturers have migrated to various ferrous and non-ferrous materials that better support temperature variations, high unit surface loading, frictional requirements, and dimensional distortions typical of today's advanced engine designs. The constant that must be maintained to ensure part function of the sealing system is the specification and consistency of the surfaces involved. There are very specialized ISO standard parameters that were designed to describe plateaued finished surfaces. These are the bearing ratio parameters (R_{pk}, R_k, and R_{vk}) and, more recently, the probability parameters (R_{pq}, R_{mq}, and R_{vq}). They monitor the peak and valley regimes of the surface, independently allowing the production team to know that the process and, therefore, the piece part, will function.

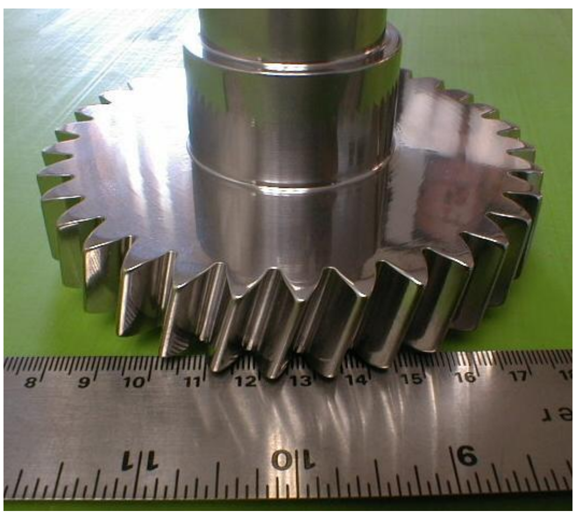

Figure 3 – Improved performance and service life can be developed with high intensity isotropic finishing methods such as centrifugal barrel finishing. (Photo credit: D, A, Davidson, SME MMR Tech Community)

Gear contact surfaces: Gears of all types must be designed to maintain their integrity under very high local surface loads (see Figure 3). The industry has always battled what material, what form, what surface will survive the varying designs and environments. Again, the surface must distribute the lube well and, at the same time, have the capability to withstand very high unit area load. Generally, the plateauing process will produce a surface free of local anomalies that can increase the local unit load and initiate a failure site. The mechanisms for surface failure are many and, sometimes, are difficult to identify. It has been found that when attention is paid to the integrity of the contacting gear surfaces by reporting the correct parameters during production, gear life is extended, noise and operating temperatures are reduced, and wear is minimized.

The Importance of surface finish design for function: The mechanism that allows for improved "functionality" for all surfaces is basic to surface performance —to accept the loads imposed and resist wear. Traditional processes that generate form and control fit do not necessarily dictate whether that part or assembly will function. Over the last three decades, it has been realized that there is another contributor to part performance—surface finish. If a manufacturer does not account for surface finish characteristics like lube retention, micro burr removal, identification of torn and folded material, directionality, and load-bearing capability, the performance of components in the system cannot be predicted. Through progressive process development, evolving measures (new ISO standard parameters), and a mature understanding of the "function" of surfaces, manufacturers can design parts that become assemblies that are in systems performing over predictable, extended lives. This is the key to reduced warranty costs, reduced scrap, lower production costs, and satisfied customers.

Case study—**Mechanical surface finish method originally justified for cost and direct labor reduction produces important performance related edge/surface effects**. Turbo-abrasive machining [TAM] is an emerging edge and surface finish technology for processing gas turbine rotating hardware. This method is used primarily for deburring and edge contour development on feature edges, especially those located on the peripheral or circumferential area of turbine and compressor discs. The process is capable of producing consistent and uniform edge and surface effects on these critical areas. Currently, much of this work is performed manually or with single point-of-contact methodologies with relatively high reject/rework rates. Although much of the economic justification for adopting TAM technologies is centered around the substantial automation of direct labor and the attendant cost reductions, an even more important consideration is the potential for improvements in part performance and functionality. The process has a number of characteristics that are potentially important for long-term service utility of components in operation. Among these is a process-developed compressive stress equilibrium—as all edge features are processed identically and simultaneously.

Very sophisticated surfaces are being developed to improve contact fatigue in gears. Vibratory, centrifugal and specialized spindle systems are being used to improve bearing load and fatigue life properties. The gear shown above was processed in a multi-sequence centrifugal operation to bring contact surfaces of the gear below 10 micro-inch R_a.

Figure 4 – Aerospace rotating hardware edge and surface finished with Turbo-Abrasive Machining (TAM). (Photo credit: Dr. Michael Massarsky, Turbo-Finish Corporation)

With TAM (Turbo-Abrasive Machining) processing, stresses on critical edge areas of features, such as those found in turbine disc broach slots, (See Figure 4) have a uniformity not possible to achieve with either manual or single point-of-contact processing; parts are also improved by changes developed on the overall surface of parts. Unlike conventional machining or grinding methods, TAM procedures develop non-linear (isotropic) surface patterns that are far less subject to potential surface crack initiation and propagation and have the added advantage of promoting surfaces with higher levels of contact rigidity for seal joint contact enhancement. Additionally, the procedure changes the nature of surface skews, traditional or conventional machined surfaces are characterized by positively skewed surface profiles in which surface peaks are the predominant surface feature. This is a surface characteristic consequence common to most all standard machining and grinding methods. Abusive machining and grinding exacerbates this natural, but undesirable, surface characteristic. In contrast, TAM surfaces are characterized by negative or neutral skews in which the surface texture pattern is far more random and multi-directional than those produced by machine cutting tools or grinding wheels. This more homogenous surface pattern has an additional functional advantage in that load bearing and wear resistance qualities of surfaces are improved as a direct result. TAM is a "cool" process that is more nonselective than traditional processing, and there is little temperature phase shift involved as the edges and surfaces of parts are altered. Two basic mechanisms are involved in this machining process: (See Figure 5)

(1) Envelopment of rotational parts within a fluidized bed of relatively small abrasive granular media, and
(2) Fixtured parts are rotated at sufficient speed to develop effective intensity interaction between part surfaces and edges, and the abrasive particles suspended and constantly replenished within the fluidized bed area.

Figure 5 – Rotating aerospace hardware can be rapidly edge and surface finished using a high-speed, dry, horizontal spindle finishing method known as TAM (Turbo-Abrasive Machining) Photo credit: Dr. Michael Massarsky, Turbo-Finish Corporation

Some Case Studies -- Edge and surface finishing for improved performance and fatigue failure resistance: The technical literature is replete with examples of case studies indicating that substantial fatigue resistance can be developed with mass finishing methods such as barrel finishing. One study published by Iron Age magazine back in 1959 documented studies on the compressive stresses to be developed with various types of abrasive and non-abrasive media in tumbling barrels.

Some processes are especially well known for this characteristic. Steel media or ball burnishing processes using vibratory techniques are known not only for producing aesthetically pleasing surfaces, but also enhancing service life of components because of the bulk-density of the media itself (300 lb./ft^3 as compared to 80 to 100 lb./cu. Ft^3 with typical abrasive ceramic media types). Some promising research has been done by major aerospace companies that indicate large air frame components can be processed to enhance fatigue life, and that fatigue life of components stressed or weakened in service can be improved during overhaul cycles as well.

Hignett, in writing a technical paper for SME in 1979, spelled out several applications where high intensity centrifugal barrel finishing was specified specifically because of the part performance and service life attributes the process could develop. Among these were:

• **Components for roller chain and silent chain**, including the slide plates, bushings, rollers and pins. The centrifugal process was able to deburr, descale, edge finish, surface finish, and impart compressive stress on the parts simultaneously. As the loose abrasive media being used in these systems are applied against part surfaces with relatively high pressure, very small media were utilized to completely and uniformly deburr and radius through holes on the side plates without rolling the burrs over. Other finishing methods could not accomplish this, and, as a result, sharp edges would be exposed when burrs were "torn" off in assembly, creating a stress raiser that would contribute to premature failure of chains due to fatigue cracks initiating at the sharp edge. Like many other similar applications, the success of this process was dependent on the process's ability to produce "holistic" changes in the parts themselves on a number of different levels. These changes not only contributed to the dimensional uniformity of the parts, permitting more automated assembly, but also changed the nature of part edge and surface characteristics and stress conditions in a way that not only facilitated extended service life, but actually made the service life more predictable.

Figure 6 – Micro-finishes are developed on dental and medical components with centrifugal isotropic finishing. (Photo credit: T. Mathisen, Mass Finishing Inc.)

• **Dental partials and orthodontic bands, brackets, and wire parts:** In recent years, high-pressure centrifugal finishing has become a standard method for producing needed edge and surface finish quality for these parts, reducing finishing costs by as much as 70% over manual methods. Given the fact that the end destination for the parts are inside the end user's mouth, uniformly consistent edge contour and very refined low micro-inch surface finishes without dimensional distortion are required. Like many demanding surface condition treatment applications, several different cycles using successively finer abrasive materials may be required to achieve the needed result. As can be imagined, the improved fatigue and wear resistance properties are product attributes that contribute to customer satisfaction considerably.

Figure 7 - Edge-finishing with mass finishing methods can improve speed and feed performance and service life of cutting tools (Photo credit: D. A. Davidson, SME MMR Tech Community)

• **Carbide and HSS tooling:** A number of different mass finishing operations are utilized by the cutting tool industry to develop edge and surface finishes on the tooling that contribute to improved cutting performance and tool longevity. Vibratory equipment, especially equipment equipped with high-frequency electro-magnetic drives, is utilized to produce uniform edge-hone or edge preparation on carbide inserts to improve cutting performance and tool life. High-pressure finishing methods, some of them employing part fixtures, are also used to produce specialized edge and surface finish effects on both carbide and HSS tooling. Among the methods employed are centrifugal barrel processing and several different variants of "drag finishing." Some processes produce edge and surface effects by pressure and compression, utilizing relatively high bulk-density non-abrasive loose media in "wet-processes." Other, more fixture-centric methods apply low bulk- density dry media with micro-fine abrasives against tooling edges and surfaces at very high rates of pressure and flow. Significant improvements in tool performance and longevity are claimed for both “new” tools and “resharps” that have edge and surface conditions modified with these types of methods. Parts currently being processed include end-mills, drill-bits, spade blades, broaches, hobs, and even circular saw blades for power tools. (See Figure 7) Several manufacturers claim tool life increases of 200 to 300% for tools processed by these methods, in some cases obviating the need for coatings.

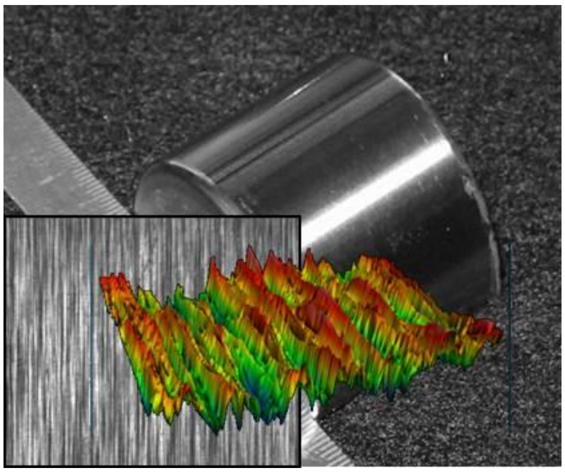

Figure 8 – Conventional surfaces produced by grinding and machining exhibit positively skewed non-isotropic surfaces such as the three views seen in this figure. (Photo courtesy of Jack Clark, Surface Analytics, LLC)

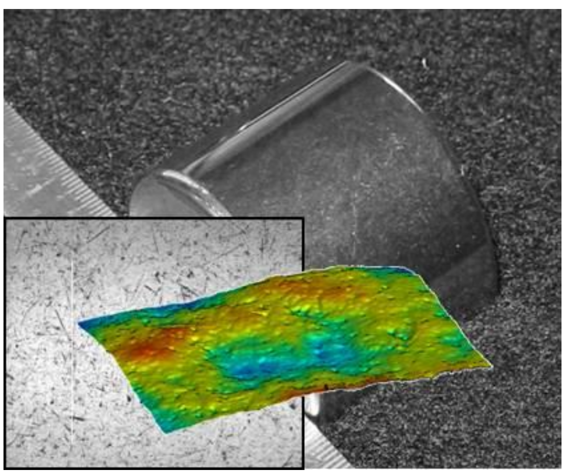

Figure 9 – This figure shows three views of the same part with isotropic surfaces with neutral surface profile skews developed with high-intensity centrifugal finishing. (Photo courtesy of Jack Clark, Surface Analytics, LLC)

• **Reed and flapper valves:** These reed components are sometimes flexed more than 12,000 cycles per minute in normal service. Centrifugal barrel finishing promotes extended fatigue life on these components by developing both generous edge-contours to limit stress concentration points, as well as simultaneously developing low-profile surfaces with high compressive stress properties. One case study cited a reduction in the number of fatigue failures developing at the predicted half-life of the part of over 95% when surface finished with centrifugal methods.

• **Stainless steel coil spring fatigue resistance:** An extensive comparative testing program was conducted to evaluate high-pressure (centrifugal barrel) methods as a means to improve fatigue life (see also Figure 8 and 9) on coil springs. In one test, the coil springs were tested to failure by depressing them from 1.104-inch lengths to 0.730 inch, developing a stress change from 0 to 50,000 psi. The coil springs processed with conventional surface finish and shot peening methods all failed between 160,000 and 360,000 cycles. Parts processed in a single, high-pressure centrifugal barrel method for 20 minutes failed between 360,000 and 520,000 cycles, a typical performance increase of 60%. All centrifugally finished parts that failed below 400,000 cycles did so because of clearly visible surface defects or inclusions. These parts could have been easily removed from the production stream by visual inspection because of the prominence of the defect, given the refined surface finish. Such defects were masked because of the highly-textured nature of the peened surfaces, making visual or optical elimination near impossible. Tests performed on another set of production springs were even more striking, with all springs processed in standard or conventional processes, failing before 600,000 cycles, and none of the same springs processed in high-pressure centrifugal methods failing before the 800,000 cycle limit of the test.

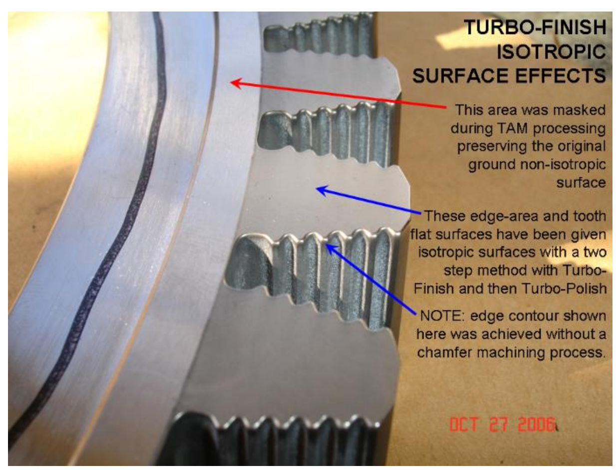

Figure 10 – Very refined surfaces can be developed on critical hardware by processing parts in several steps with successively finer abrasive or polishing materials. (Photo courtesy of Dr. Michael Massarsky, Turbo-Finish Corporation)

The importance of edge and surface condition quality: Deburring and surface conditioning has often been treated as the "poor relation" or "step-child" of manufacturing engineering. Many parts and components have been shown to have sub-optimal performance because of a lack of edge and surface-quality conscious design. Edge and surface finish can be an important factor in driving ultimate part performance and functionality. In what has become a standard reference on the subject, ("Deburring and Edge Finishing Handbook") author LaRoux Gillespie enumerated 25 different potential problem areas that might result from insufficient care being given to edge and surface finishing process selection. They are:

- cut hands in assembly or disassembly;
- interference fits (from burrs) in assemblies;
- jammed mechanisms (from burrs);
- scratched or scored mating surfaces (which allow seals to leak);
- friction increases or changes (disallowed in some assemblies);
- increased wear on moving or stressed parts;
- electrical short circuits (from loose burrs);
- cut wires from sharp edges and sharp burrs;
- unacceptable high-voltage breakdown of dielectric;
- irregular electrical and magnetic fields (from burrs);
- detuning of microwave systems (from burrs);
- metal contamination in unique aerospace assemblies;
- clogged filters and ports (from loose burr accumulation);
- cut rubber seals and O-rings;
- excessive stress concentrations;
- plating buildup at edges;
- paint buildup at edges (from electrostatic spray over burrs);
- paint thin out over sharp edges (from liquid paints);
- edge craters, fractures, or crumbling (from initially irregular edges);
- turbulence and non-laminar flow;
- reduced sheet metal formability;
- inaccurate dimensional measurements;
- microwave heating at edges;
- reduced fatigue limits;
- reduced volumetric efficiency of air compressors;
- reduced cleaning ability in clean room applications;
- reduced photoresist adherence at edges;
- and to the list we would add less aesthetic appeal.

To summarize, are we certain that we clearly understand how edge and surface finish quality might contribute to how manufactured parts and components will function, perform and last in service? Tools are readily available. Will we use them? To an increasing degree, to borrow a well-worn phrase used by one finishing compound manufacturer, "It is the finish that counts." □

Further reading: Internet resources

(1) **"**Isotropic Mass Finishing for Surface Integrity and Part Performance", Article From: *Products Finishing*, Jack Clark, from Surface Analytics, LLC and David Davidson, from SME Deburr/Finish Technical Group, Posted on: 1/1/2015, [Barrel, vibratory, centrifugal and spindle finish can improve part performance and service life.] http://www.pfonline.com/articles/isotropic-mass-finishing-for-surface-integrity-and-part-performance

(2) "Turbo-Charged Abrasive Machining Offers Uniformity, Consistency" Article From: *Products Finishing,* by: Dr. Michael Massarsky, President from Turbo-Finish Corporation, and David A. Davidson, from SME Deburr/Finish Technical Group. Posted on: 6/1/2012. [Method can deburr, produce edge contour effects rapidly] http://www.pfonline.com/articles/turbo-charged-abrasive-machining-offers-uniformity-consistency

(3) "Turbo-Abrasive Machining and Finishing". *MANUFACTURING ENGINEERING – Aerospace Supplement*, by: Dr. Michael Massarsky, President from Turbo-Finish Corporation, and David A. Davidson, from SME Deburr/Finish Technical Group. [Method first developed for the aerospace industry can improve surface integrity and part performance] http://www.slideshare.net/dryfinish/turboabrasive-machining-me-aerospace-supplement-reprint

(4) "The Role of Surface Finish in Improving Part Performnce", *MANUFACTURING ENGINEERING,* by Jack Clark, Surface Analytics.com and David A. Davidson, from SME Deburr/Finish Technical Group. http://www.slideshare.net/dryfinish/november-2012-f4-deburring-1-final

(5) "Free Abrasives Flow for Automated Finishing", *MANUFACTURING ENGINEERING,* , by: Dr. Michael Massarsky, President from Turbo-Finish Corporation, and David A. Davidson, from SME Deburr/Finish Technical Group. [Exciting new methods of surface finishing that go beyond deburring to specific isotropic surface finishes that can increase service life] http://www.slideshare.net/dryfinish/october-2013-f2-deburring-1

(6) Turbo-Abrasive Machining Demonstration Video: https://www.youtube.com/watch?v=jYxqCxMIHNo

(7) SME Spokane, WA Factory Floor video, *Centrifugal Finishing in the Precision Machine Shop: Demonstration)* https://www.youtube.com/watch?v=dUdKjaysTYM