Dr. Michael L Massarsky
TURBOFINISH CORPORATION
P. O. Box 344
Barre, MA 01005 USA
phone; 917.518.8205
e-mail: michael@turbofinish.com
David A. Davidson
SME Technical Community Network,
Colville, WA 99114 USA
phone: 509.230.6821
e-mail: dryfinish@gmail.com

Turbo-Abrasive Machining: Dry, High-Speed Automated Isotropic Finishing of Turbine Rotating Parts

INTRODUCTION: Turbo-Finish technology (also referred to as Turbo-Abrasive Machining) is a dry, high-speed spindle finishing process that utilizes abrasive fluidized bed technology, and high speed part rotation to develop extremely rapid and uniform edge and surface conditioning on aerospace, automotive and industrial parts. Polishing, deburring and edge radiusing are accomplished anywhere that the media can access. This finishing technology can develop isotropic surface finishes s while developing consistent round edges on any exposed sharp edged features.

Many critical machined parts and components have burr and edge conditions that require substantial deburring and edge and surface finishing prior to being ready for final assembly and introduction into service. Burrs, sharp edges, and rough surfaces must be replaced with radiused edges and smoother isotropic surfaces to prevent problems associated with premature fatigue or wear failure of the parts while in service. Stress risers must also be eliminated and replaced with a compressive stress condition if premature part failure is to be avoided. This is especially true in the aerospace and other industries whose parts are subjected to repeated stress in operation.

ABSTRACT

Turbo-Abrasive Machining [TAM] is a mechanical deburring and finishing method originally developed primarily to automate edge finishing procedures on complex rotationally oriented and symmetrical aerospace engine components. Since its inception this method of utilizing fluidized free abrasive materials has facilitated significant reductions in the amount of manual intervention required to deburr large components by these manufacturers. Additionally, the process has also proved to be useful in edge and surface finishing a wide variety of other non-rotational components by incorporating these components into fixturing systems. The advantages of this method go beyond the simple removal or attenuation of burrs. The method is also capable of producing surface conditions at critical edge areas that can contribute to increased service life and functionality of parts that are severely stressed in service. Among these are: (1) the creation of isotropic surfaces. (2) the replacement of positively skewed surface profiles with negative or neutral skews and (3) the development of beneficial compressive stress.

One of the distinctive features of TAM that contrasts it with other mechanical or mass media finishing techniques is its more familiar human/machine interface. Operators familiar with PLC or CNC controlled machines for milling, turning or grinding will feel at ease with

Figure 1 - Model Tf-522 Turbo-Abrasive Machining Center For Deburring And Edge Contouring Turbine Disks Up To 500mm In Diameter.

TAM controls. The major difference between TAM and these methods is the tooling. Unlike the single-point-of-contact tooling used by other machining techniques, the unique TAM abrasive

Diagram Showing Formation of Abrasive Fluidized Bed

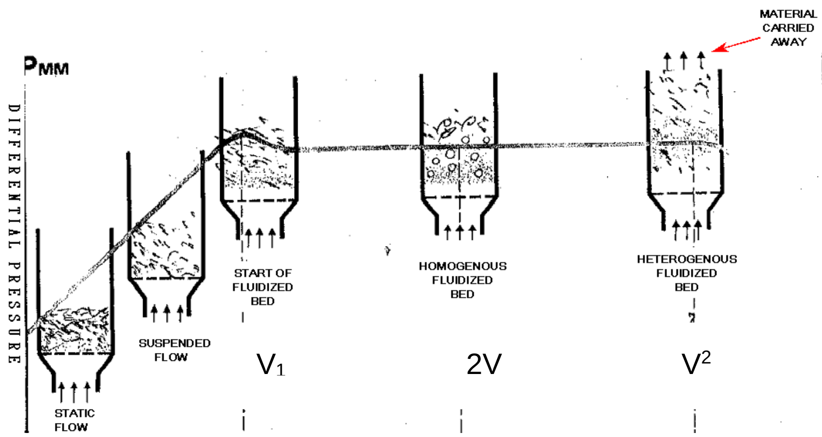

Figure 2 - Critical Air Flow Speed (Velocity)

fluidized bed technology makes it possible to machine all the features of rotating components simultaneously. This processing attribute promotes a uniformity of edge/surface conditions and stresses not possible to duplicate with any single-point-of-contact method.

Turbo Abrasive Machining (TAM) is a new process for deburring, edge contouring and surface conditioning complex rotating machined parts. Many of these types of parts, because of size and shape factors, can not be finished by a mass media technique but need manual intervention for final abrasive finishing. Apart from safety and production line/time considerations, a significant disadvantage of manual deburring is its impact on quality control and assurance procedures that have often been computerized at great cost. The TAM process addresses these problems by automating the final machining and finishing production steps.

In TAM, fluidized bed technology is utilized to suspend abrasive materials in a specially designed chamber; part surfaces are exposed to and interact with an abrasive fluidized bed on a continuous basis by high-speed rotational or oscillational motion in an entirely dry environment. This combination of abrasive envelopment and high-speed rotational contact can produce important functional surface conditioning effects and deburring and radius formation very rapidly. Because abrasive operations are performed on all features of rotating components simultaneously, the part and feature uniformities achieved are very hard to duplicate by other methods. In addition, sophisticated computer control technologies can be applied to create processes tailored for particular parts. [Figure 1]

Although the abrasive materials used for TAM processing are in some ways similar to grinding and blasting materials, the surface condition produced is unique. One reason for this is the multidirectional and rolling nature of abrasive particle contact with part surfaces. These surfaces are characterized by a homogenous, finely blended abrasive pattern developed by the non-perpendicular nature of abrasive attack. There is no perceptible temperature shift in the contact area and the finely textured random (isotropic) abrasive pattern is a highly attractive substrate for subsequent coating operations.

TAM Process Elements. Turbo Abrasive Machining (TAM) technology depends on utilizing relatively small free abrasive grains to access intricate part shapes. Unlike blasting or other impact metal finishing methods, the mechanism behind TAM processes utilize a combination of kinematic forces to produce unique and distinctive edge and surface finishes on complex and intricate parts which can not be processed with other automated deburring or finishing methods, and usually are processed with manual deburring techniques. These two forces act synergistically and are mutually dependent. They consist of (1) envelopment of the part with abrasive grain suspended in a fluidized bed and (2) interfacing part edges and surfaces with abrasive grain by rotational motion of the part.

TAM technology has several advantages in comparison with other mechanical finishing processes. Some of these advantages are:

- A High flow of free abrasive grain allows for penetration of abrasive media particles into difficult to access part areas that require edge and surface finish improvement.

- Low energy consumption; especially in contrast to pressure blast surface finishing.
- Very simple tooling, processing, and maintenance requirements;
- Combination of rapid deburring and high rates of metal removal with significant improvements in the physical and mechanical properties of metal surfaces that can enhance surface integrity. These changes include developing: residual compressive stress, surface isotropicization, surface profile skewness correction, contact rigidity and load bearing ratio improvements.

Fluidized Bed Principles. Abrasive grain can be suspended in a work chamber by airflow introduced to the compartment. (Typically, fluidized beds are understood to be contained granular or powder materials that take on the properties of a liquid by introducing a controlled air stream to them. [Figure 2]) The velocity and nature of the particle movement can be expressed mathematically. Collision between particles initiates their rotation, and gives rise to what is referred to as the "Magnus effect" the

Figure 4 - After TAM Processing, sharp edges have been replaced with polished edge contoured. Two TAM processes with sequentially finer abrasive material were ssed.

angular velocity of particles contributing to their random and chaotic motion in the fluidized bed. Unlike other deburring and finishing methods however, the primary energy that produces the abrasive effect is not in the abrasive media but in the rotational motion of the part. Experimental analysis has determined the relationship between rotational speed and the depth and length (measured here in microns) of abrasive tracks measured on part surfaces. With peripheral speed measured in meters per second, the following table shows the effect of increasing speed on the size of abrasive tracks made by 30 mesh grains.

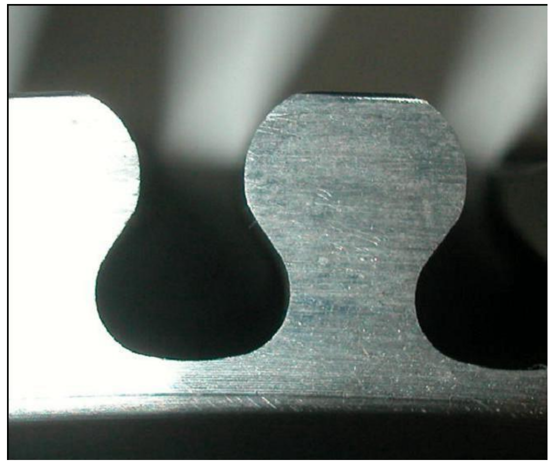

Figure 3 - Dovetail slot feature on turbine disk with sharp edges prior to TAM processing

Rotational speed also affects the concentration of abrasive tracks in a given area; the table (TABLE 1) shows the number of abrasive tracks to be found in a square millimeter as speed is increased.

Turbo-Abrasive Machining processes in production often achieve part peripheral speeds in the 20-30 m/s (meter per seconed) range, the value for abrasive tracks in a given square millimeter at this speed can be as high as 500 per mm^2 per second. This random pattern of abrasive tracks can be very useful functionally in that the surfaces produced are isotropic in nature.

Metal removal is determined by several factors, including:

the amount of media particle pressure generated on the surface, and by the high frequency and density of abrasive particles and part surface collisions, which can approach (3-5)*10^2 1/s*mm^2. The calculations carried out by formula (1) have shown that:

$$V_{\min} = \frac{3[\delta]t}{\pi(k+1) fR_p}\left(\frac{1}{E_a}+\frac{1}{E_m}\right)^2 \qquad (1)$$

where:

δ - metal fluidity limit;
t - contact time (abrasive and surface);
k - recovery coefficient;

f - abrasive grain density;
R_p - medium radius of grain projection;
E_a, E_m - elasticity modula of abrasive grain and metal

Figure 5 - 400x Microphotograph shows abrasive tracks on part surfaces from TAM processing

...the minimum speed of interaction required to produce metal plastic deformation on components made of structural steel and ground by abrasive particles with a dimension equal to Dg = 160 - 630μm is V_{min} = 1.42 - 0.83 m/sec. Thus media particle action generated within the fluidized bed at a speed equal to 0.1 - 0.5 m/s is insufficient by itself for effective treatment of metal surfaces and edges. Additional velocity is required to impart sufficient intensity to part surface and abrasive grain contact. The needed velocity can be developed either by rotational movement or high-frequency oscillation. With the increase of peripheral speed of a part the force action of the abrasive pressure (i.e., contact between part features and the fluidized bed of abrasive grain) on the surface being machined significantly increases, thus intensifying metal removal edge contouring, and surface texture formation. The abrasive particle pressure value is calculated by formula (2) shows:

$$P_{fd} = (k+1)\, f\, (1-\varepsilon)\, (V_g+V_p \sin\theta \sin ß)^2 \qquad (2)$$

where:

1-ε - abrasive grains concentration on a unit volume of fluidized bed;
V_g - speed of abrasive grain movement;
V_p - speed of a part movement;
f – abrasive grain density
θ-angle inclination of sides of machining/grinding surface tracks;
ß - angle between the direction of machining track pattern and part speed vector;

Interaction of the main variables of the (TAM) process, include: abrasive grain parameters: D_g fluidized bed parameters ε, V_g; kinematic parameters V_p; surface roughness parameters θ, ß and mechanical parameters k, of the surface being machined.

Calculations show that with a change of V_p from 10 m/sec to 25 m/sec the values of P_{fd} are equal to 0.1 - 0.5 MPa. Grain pressure value on a surface being machined varies considerably depending on the surface orientation in relation to the fluidized bed of abrasive particles. The optimum surface disposition or orientation increases the P_{fd} value 1.2 - 2.6 times; the process productive capacity and efficiency figures will grow correspondingly.

Figure 6 - Turbo-Abrasive Machining processes make it possible to edge contour and surface finish part features and geometries not accessible by other finishing methods. This ability is facilitated by both the relatively small size of the abrasive media and the high pressure nature of the part surface and media interaction.

A study of track marks made by individual particles illustrates that the length of scratch marks can grow considerably when the rotational speed of the part is increased. So with an immobile part the medium length of scratch Lm when grinding by silicon carbide particles with a dimension of grain (D_g) = 630μm is 8μm

Thus the transition from processing an immobile part in the abrasive fluidized bed to processing the part by adding rotational movement at a peripheral speed rate of 15 m/sec increases the productive capacity of metal removal volume 200 - 300 times and is equal to 3-7 μm/min depending on physical and mechanical characteristics of the metal to be machined.

The volume of a single microscratch is determined by considering a single microscratch as a part of an ellipsoid. The calculations carried out by formula (4) have shown that:

$$\overline{V}_{avg.} = \frac{\pi}{8} \text{ x } \overline{l} \text{ x } \overline{b} \text{ x } \overline{h} \qquad (4)$$

Where

TABLE 1 Rated and experimental values of parameters of $\overline{h}$, $\overline{l}$, $\overline{b}$, and Q_m.

Vp m/s	**$\overline{h}$(cal) μm**	**$\overline{h}$(exp) μm**	**$\overline{l}$(cal) μm**	**$\overline{l}$(exp) μm**	**$\overline{b}$(cal) μm**	**$\overline{b}$(exp) μm**	**Q_m(cal) mm^3/min**	**Q_m(exp) mm^3/min**
5	0.49	0.63	23.2	19.8	1.92	2.40	0.37	0.30
10	0.61	0.65	41.4	30.6	2.44	2.51	1.01	0.86
15	0.75	0.68	59.4	57.0	3.0	2.6	1.78	1.55

Research performed also indicates that the (TAM) process accomplishes edge and surface improvements as a result of micro-cutting action and slightly cycled fatigue destruction. Weak forces acting on a grain and low viscosity of the fluidized bed produce the low temperature operating characteristic of TAM; this accounts for the process's low energy consumption. (Specific power consumption is equal to 0.12 - 1.5 W/cm^2).

Mathematical models permit us to calculate the value of abrasive particle pressure on a given surface and the functional relationship of the intensity of metal removal.

Intensity of Metal Removal – Theoretical Definition.

$$Q_m = Y_m \text{ x } V_{avg}. \text{ x } N_{gr}. \text{ x } P_{fr} \qquad (3)$$

Where:

Y_m - material density to be machined;
V_{avg}. - an average volume of a single microscratch;
P_{fr} - a coefficient to bear in mind in correlating of cutting and friction processes of Turbo-Abrasive machining;
N_{gr} - is the statistical average of the number of grains a surface square unit per time unit

$\overline{l}$, $\overline{b}$, $\overline{h}$ - average values of length, width, and depth of a microscratch respectively.

The microscratch depth is determined by the impact theory. The calculations carried out by formula (5) show:

$$\overline{h} = 1.7K_h \text{ x } \overline{b}_m \text{ x } \overline{D}\,gr. \text{ x } (V_{gr.} + V_p \text{ x } \sin\theta \text{ x } \sin\beta)^{3/4} \qquad (5)$$

where
K_h - proportionality coefficient
b_m - metal plasticity constant.

The microscratch length is determined as a path passed by grain during the contact. The calculations carried out by formula (6) show:

$$l = \frac{(2 - K_h) \text{ x } h \text{ x } \Phi \text{ x } \cos\theta}{V_{gr.} \text{ x } \sin\theta} \qquad (6)$$

Where:
Φ - tabulated function in terms of metal plasticity constant value *b(m).*

The width of a microscratch *"b"* by modeling the apex angle with rounding cone based upon the correlation *b = 4h.*

Taking into consideration the obtained formulas for *h, l, b,* $V_{avg.}$ and $N_{gr.}$ the calculations show the

$$Q_m = 33Y \times K^3_h \times (2-K_h) \times P_{fr} \times \qquad (7)$$

$$\cos\theta \times \bar{b}(m) \times \bar{D}_{gr.} \times (V_{gr.} + V_p \times \sin\theta \times \sin\beta)$$

metal removal intensity as follows:

Table (1) [previous page] shows the data of Q_m values, obtained for steel machining by abrasive grain of Al O and size 36 US Mesh.

Surface Finish. In Turbo-Abrasive Machining high-frequency micro-impact interaction of abrasive grains can produce a surface micro-relief and outer metal structure that improves part operational and functional properties. TAM processes can achieve surface roughness values R_a 0.2 - 0.4 μm for various steels and alloys, from a starting roughness Ra 3 - 5 μm. The technology makes it possible to develop homogeneous micro-relieved surface textures. After Turbo-Abrasive Machining: the ratio R_{max}/R_a equals 6 - 8 while after conventional grinding:
the ratio R_{max}/R_a is equal 10 - 12.

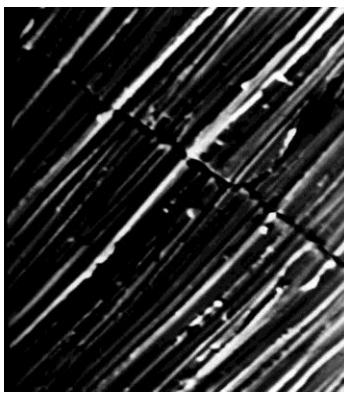

Figure 7 - This photograph at high magnification shows the surface [profile of an as ground surface. The is a positively skewed surface with surface peaks the predominant characteristic.

Productive Capacity of the Turbo-Abrasive Process. Analysis and experimental investigations of Turbo-Abrasive Machining processes has shown that metal removal intensity - Q_m depends on several variables, the principal ones being:

- rotational speed of a part
- machining time
- air discharge
- median size of abrasive particles
- physical and mechanical properties of a machining material ~ condition of initial surfaces
- direction of surface micro-unevenness in relation to the vector of part velocity

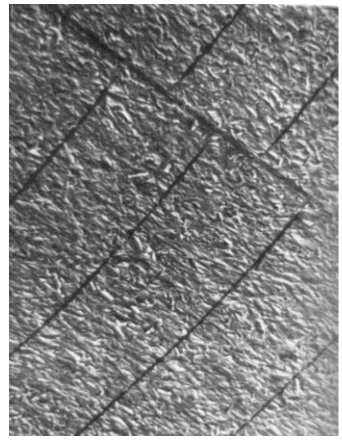

Figure 8 – This highly magnified photograph shows surface characteristics ofter TAM processing. Note the random nature of the surface pattern typical of isotropic surfaces

The abrasive action in the TAM process is very stable. The abrasive grain used as the cutting tool nmaintains its cutting ability for extended periods of time. This is because after the initial break-in of the grain, the continual impacts of grain with part edges and surfaces develop new cutting edges. Abrasive materials of the aluminum oxide group are used in Turbo-Abrasive Machining and also alloyed abrasive materials from the zirconium and chromium-titanium families, with grain affect 160-800 μm, having high impact strength. Productive capacity of Turbo-Abrasive machining depends on part velocity. The output of metal volume increases 2.8-4.0 times with increasing of velocity speed from Vp = 10 m/sec up to Vp = 20 m/sec. Analysis has shown that metal removal rate decreases with further increasing of part velocity up to Vp = 30 m/sec. This is due to the formation of an air boundary that effectively prevents part surface/abrasive grain collisions. The values Qm increase 2.1 - 2.6 times with media size increasing from 100 μm up to 800 μm. Metal removal rate dependence on rotating part air stream velocity and turbulence is external and proves that air flow increase leads to an air boundary layer volume expansion and consequently, to abrasive particle concentration decrease interacting with a surface unit, and to a decrease in abrasive action output. Air flow and abrasive particles are linked by parabolic dependence. While machining continuous aerodynamically well flowed surfaces, an abrasive particle will not lose its cutting ability for a long time; when machining discontinuous surfaces the stability of media particle abrasiveness decreases more rapidly because of intensive frontal impacts with more abruptly shaped part surfaces.

Physical and mechanical properties of the metal alloy being processed influence the quantitative results only, not changing the overall process characteristics. It is estimated that a surface roughness initial direction in relation to a vector of a part peripheral speed essentially intensifies both the metal removal rate and metal micro-relief formation.

Deburring and Radius Formation. When machining complex parts, burrs typically appear on all part edges. Mechanical deburring is one of the foremost applications for this technology. TAM processes can provide cost-effective and productive solutions for demanding applications of this type.

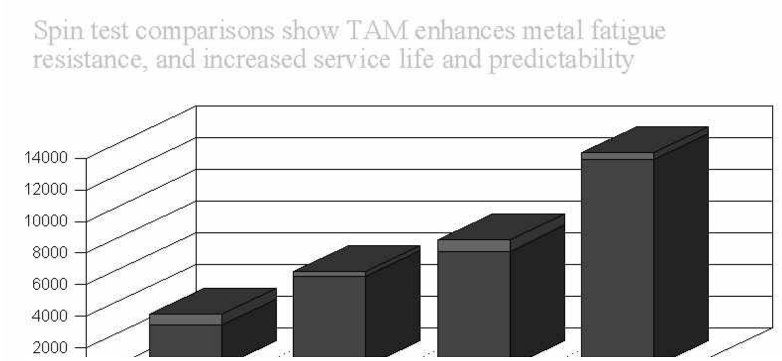

Figure 9 - TAM and manual deburr methods contrasted for part life expectancy

One characteristic of Turbo-Abrasive Machining is the high fringe effect (i.e., more intensive machining or finishing of edges and areas closer to the circumference) effective deburring and edge contouring and finishing has been performed on this basis. Special examinations have been carried out concerning this technology with regard to deburring and rounding off edges after various machining procedures. Burrs were formed on two types on steel disk samples: after drilling the disk openings 10 mm across; after groove milling; the groove width is 10 mm in the periphery of disk.

The initial length (bracket) of burrs after drilling reached Lo=0.3 - 0.6mm; after milling Lo = 1.8-2.3 mm. The burrs were removed at rotational speed Vp equal to 5, 10, 20 m/sec. Here aluminum oxide was used, with a grit value Dg = 500; 800 μm. Burr measures were taken by microscope with a measuring error of approximately 3%.

It is established experimentally that burrs are removed completely after being drilled, at V_p = 10 m/sec. If Vp increases up to 20m/sec, time of machining decreases and is equal only to 3 min. Burr removal intensity increases 2-4 times in parallel with the rotational speed increase from 10 to 20 m/s in deburring process after drilling, and the grit increasing D_g from 500 to 800 μm - up to 3 times This fact can be explained by the kinetic energy and impact frequency increase. These investigations have shown that Turbo-Abrasive Machining makes it possible to deburr alloys and metal materials of high plasticity and also stainless steel parts. On brass alloys sample burrs were removed at V_p = 20m/sec, but on stainless steel samples the burr removal took 4-6 min. TAM-technology allows simultaneous deburring and rounding off edges. Special investigations made it possible to define the optimum combination of different technological parameters to achieve the radii of rounding off the edges up to R = 1.2 mm. As far as one can see from any change of a part speed from V_p = 10 m/sec up to V_p = 24 m/sec increases the edge radius 1.7 -2.9 times. The radius value grows 3 - 3.4 times with grain size growing from 250 μm up to 800 μm. This effect of grain influence is connected with the fact that the impact energy of the grain and the surface being machined is proportional to the mass of abrasive grain. The angle between the edge direction and the velocity vector of a part essentially influences on the radius of rounding off edges. The edge radius increases 4.1 times on the average and equals to 1.0 - 1.2 mm with the angle change from α = 0 up to α = 30. Therefore it is possible to operate both the deburring and the radius formation processes by changing the process regimes. On the basis of these experiments and investigations a technology of mechanized deburring has been developed for such parts as gear wheels, gas-turbine disks, parts after stamping, etc.

Part Life Expectancy Improved. In contrast to conventional grinding Turbo-Abrasive processes are noted for their low temperature "cool" operating characteristics, minimizing undesirable effects to the surface layer of parts being treated. Turbo-Abrasive Machining also enhances the metal fatigue resistance important to many rotating components by developing residual compression stresses with MPa = 300 - 600 that are formed on a surface layer of metal in the depth of 20 - 40 μm (Figure 6); micro-roughness shapes are characterized by large radii of rounding off Rpr = 200 - 400 μm as well as small slope of the sides Θ = 0.8 - 1.6 These characteristic residual compressive stresses in combination with the absence of single deep scratches can result in significant increases in rotating component fatigue strength.

Experiments which consisted of high frequency bending and flexing of steel plates for fatigue strength testing showed marked fatigue strength improvement on the plates which had been processed with TAM methods. The plate specimens were tested with a vibratory amplitude is 0.52 mm, and load stress of 90 Mpa. The destruction of specimens machined by the Turbo-Abrasive method started after:

$(3 - 3.75) * 10^4$ cycles

and the destruction of conventionally ground plates started after:

$(1.1 - 1.5)*10^4$ cycles.

The results obtained from gas-turbine engine longevity testing are of great interest. Comparison tests were made on disks manufactured of titanium alloys and high temperature nickel alloys that were machined by Turbo-Abrasive technology and manual grinding and polishing technologies.

Turbo-Abrasive Machining the average result for the fatigue limit value σ_1 amounts to 330 ± 20 Mpa

while after manual grinding treatment the value σ_1 was equal to 250 ± 43 MPa.

Thus TAM-technology increases the value σ_1 1.3 times, at the same time decreasing the value of dispersion σ_1 more than two times. Comparisons were also made with gas-turbine disk spin tests. These tests were carried out in special equipment stands to produce conditions equivalent to the disk stress load when a jet engine is in operation. The following parameters were specified in the test reports:

the number of cycles before scratches appeared; (length up to 0.3mm) - Nsc;
the number of cycles before the disk destruction - Ndes.

It has been found out that the disks after Turbo-Abrasive treatment have the values:

Nsc = 7300 ± 700 cycles,
Ndes = 13090 ± 450 cycles

while after manual treatment they have the values:

Nsc = 2600 ± 700 cycles
Ndes= = 5685 ± 335 cycles.

These tests indicated that Turbo-Abrasive machining has been shown to be capable of increasing the service life of disks 2.2 - 2.5 times, making improved engine utilization possible.

Contact rigidity is important characteristic that can ensure reliability and sealing of detail joints during assembly. Testing has shown that the contact rigidity of steel part surfaces after Turbo-abrasive machining can be increased by 50 - 60% in comparison with conventionally ground surfaces.

Other useful operating surface characteristics after Turbo-Abrasive machining include improved bonding with various coatings, (electrodeposited, plasma coatings, etc.) and also reliable retention of lubricant film. One test revealed that oil consumption for piston rings after Turbo-Abrasive machining decreases by 2.5 - 4.0% in relation to fuel consumption.

Equipment and Fields of Application. This equipment aimed at machining of parts from 50 - 1200 mm has been developed and used in for deburring, edge contour and surface integrity improvement in various aircraft engine manufacturing plants in the USA.

There are different types of Turbo-Abrasive equipment designed for multiple and mass production. The Turbo-Abrasive process is performed in automatic cycle; the operator's duty is only to load and unload the workpieces. The productive capacity of the equipment can be as much as 60-80 pcs/h.

The process of Turbo-Abrasive machining proves to be highly effective in solving the following technological problems:

· Deburring after machining operations as well as after stamping;

· Edge break and controlled radius formation;

· Improving surface roughness values to Ra = 0.2 - 0.4 μm [Ra = 1.36 – 10 μin.] for components made of structural and stainless steel, high-temperature, non-ferrous and titanium alloys;

· Substrate preparation before coating;

· Descaling after thermal treatment, carbon deposit removal, etc.

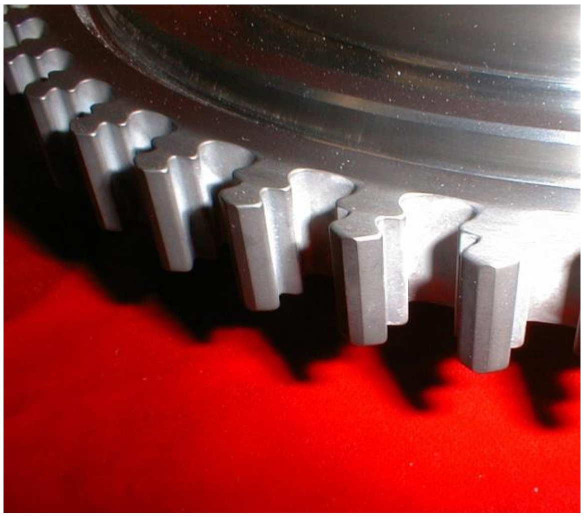

FIGURE 11 – TYPICAL EDGE CONTOUR ON SIMILAR FEATURES AFTER TAM PROCESSING.

While solving these edge and surface finish problems Turbo-Abrasive machining makes it possible to mechanize and automate labor-intensive manual operations, to increase productivity 3 - 10 times, and to improve and stabilize the quality of machined components.

Turbo-Abrasive Machining is being used in edge-finishing turbine and compressor disks, and other gas-turbine engine components manufactured of high-temperature and titanium alloys for the aircraft and power industries.

Testing has shown that the fatigue strength limit of disks increases by 26 -38%. when TAM is used as a mechanical finishing process. High efficiency is a distinctive feature of the Turbo-Abrasive machining of gear-wheels in the

FIGURE 10 - BURR AND EDGE CONDITION PRIOR TO TAM PROCESSING

process of deburring and rounding off the edges after gear-tooth cutting. This technology is also used in the automotive industry for rotor machining of mechanisms for turbo-charging. The new method has been also used for finishing treatment of piston rings. Testing has shown that achieved piston ring surface micro-relief contributes to better lubricant film retention as well as decreasing lubricant consumption. TAM technology can be successfully applied in machining diamond cut-off wheels and circular saws. It has also been used on agricultural machinery such as shearer comb-cutters for sheep shearing, processed after tooth cutting, 186 comb-cutters being processed simultaneously, with a process time of 10 minutes (i.e. 3 - 5 seconds for each comb-cutter).

All of the above mentioned applications illustrate a wide range of possibilities for Turbo-Abrasive machining, which can be applicable where other technologies can not be used or are less effective. This new method can provide manufacturers the capacity to finish complex parts cost effectively, and develop surface finish characteristics that are more refined and more functionally useful than the manual or conventional methods being currently utilized. (Before and after examples. See Figures 12 – 16)

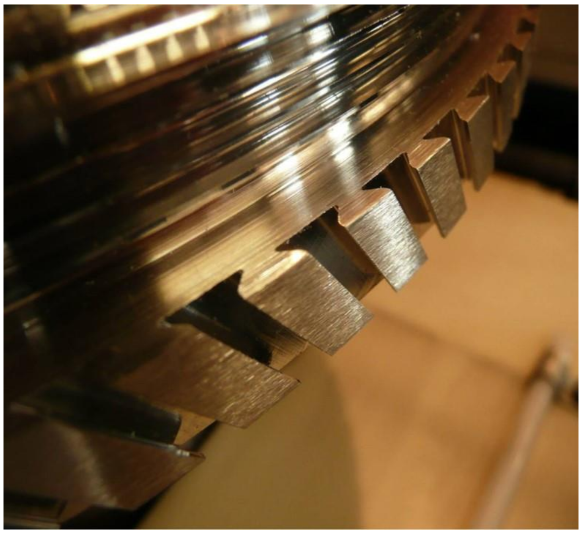

Figure 12 - Detail of compressor disc prior to Turbo-Abrasive Machining and Finishing.

Figure 13 - Detail of compressor disc following a Turbo-Abrasive Machining and Finishing process. This automated dry process deburrs, edge-contours and develops isotropic surfaces simultaneously.

.Figure 14 - Detail of turbine disc prior to Turbo-Abrasive Machining and Finishing.

Figure 15 - Detail of turbine disc following a Turbo-Abrasive Machining and Finishing process. This automated dry process deburrs, edge-contours and develops isotropic surfaces simultaneously.

Figure 16 – The Turbo-Finish processes utilize high speed part rotation and abrasive fluidized bed technology to deburr and finish complex rotating shapes in a rapid dry-process horizontal spindle finish method. The automated method can reduce deburring cycle times from hours to minutes.

Summary:

The Turbo-Abrasive Machining process is a significant new process for developing important edge contour and surface finish effects on a wide variety of complex and difficult machined parts. These kinds of machined parts currently pose a challenge that can not be fully met by conventional finishing methods, and often require tedious and labor-intensive manual methods. Turbo-Abrasive Machining is a method that allows for automation of these difficult tasks in a dry abrasive environment that minimizes waste disposal and the incidence of deburring operation related repetitive motion injuries. It also significantly improves productivity and feature-to-feature, part-to-part, and lot-to-lot uniformity, while at the same time enhancing the surface integrity and service functionality of critical hardware. □

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

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