SURFACE INTEGRITY PROCESSING GUIDELINES

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WHY DO WE NEED GUIDELINES?

There is an increasing awareness that surface integrity can have a significant impact on product integrity. Both the surface topography and the subsurface altered material zones (AMZ) can influence longevity and reliability of a component. The demands for specific data on each material and process combination can not yet be met. Until reliable data are on hand, sets of guidelines have been generated to help design and manufacturing engineers. The references on the last page provide some of the latest specific information.

PROCESSING LEVELS

It is necessary to consider the level or intensity of processing used in assessing the impact of a process on material properties. The terminology in use today considers three levels of processing intensity:
- Finishing or low-stress or gentle
- Conventional or “standard” conditions
- Roughing or “off-standard” or abusive

Emphasis should be placed on defining the exact operating parameters used to obtain the particular state described by one of these terms. Data on at least two levels of intensity should be available so that the manufacturing leeway available around the selected operating conditions can be known. These data are invaluable in setting the quality control limits.

PRECAUTIONS IN USE OF SURFACE INTEGRITY GUIDELINES

- The following guidelines are meant to serve as general or starting recommendations only. Data and experience gathered to date indicate that these practices will lead to increased surface integrity. However, knowledge of the state of surface alterations at this time is such that general recommendations are not always applicable to all specific surface integrity situations. For highly critical or highly stressed surfaces, it is mandatory to make individual specific evaluations.

- Surface integrity control generally results in increasing costs and decreasing production rates. Therefore, surface integrity practices should be implemented only where a definite need exists. Process parameters which provide surface integrity should be applied selectively to critical parts or critical areas of given parts to help minimize costs. If noncritical areas or parts are relaxed in tolerances for surface integrity, cost improvements can be achieved. A detailed study of the surface requirements can achieve these savings.

- The guidelines are intended primarily for processes used in producing the final or finished surface of a workpiece. It is important to know the depth of surface alterations produced during the roughing operation so that adequate provision can be made for removing any damaged layers. The sequence of operations is as important as the specific processing level.

- Ample recognition must be given to the necessity for relentless and implacable process control once the desired surface integrity processing parameters have been selected. Equal consideration for control of the metallurgical state and condition of the material being presented for processing is essential.
KEY INDICATORS OF NEED FOR SURFACE INTEGRITY CONTROL

- Distortion in thin parts.
- Cracking in processing or in service.
- Short service life.
- Requirements for manufacturing parts using sensitive alloys such as high strength steels, nickel and cobalt base high temperature alloys, titanium alloys, beryllium, and refractory alloys.
- New or indeterminate environmental conditions including stress, temperature, and atmosphere.
- Hazards to life and/or the possibility of high economic property loss.
- Requirements for designs which approach more complete utilization of material properties.

POST-TREATMENT OR PROCESSING

To enhance surface integrity, various post-processing operations are employed. The surface integrity produced from each of them should be assessed with the same diligence used in the prime processing. Some guidelines for post-processing are:

- Heat treatments following material removal are of limited usefulness.
- Low temperature heat treatment to remove hydrogen picked up during processing is desirable.
- Careful washing should be employed to remove all traces of cutting fluids or electrolytes that could cause stress corrosion.
- Abrasive tumbling is an effective process for improving surfaces for fatigue strength.
- Steel shot and glass bead peening can be used to improve surface integrity and fatigue life.
- All heat affected layers created during processing should be removed from critically stressed parts. Suggested removal methods are: mechanical polishing, sanding, low stress grinding, honing, chem milling, electropolish.

GENERAL MATERIAL REMOVAL GUIDELINES

At this time, most of the surface integrity investigations and data collecting has involved material removal processes. This pamphlet will, therefore, be confined to this major processing group. This does not indicate that forming, coating or other processes are exempt from surface integrity considerations, only that insufficient data is on hand. The most detailed set of guidelines is in Reference 1.

Some general guidelines for all material removal processes are:

- Education and training for designers, shop supervision, quality control and process engineers is essential to increase their appreciation of the magnitude of surface integrity effects from manufacturing processes.
- Rigid high quality machine tools and fixtures are desirable.
- All processing parameters should be specified completely by manufacturing engineering and rigidly monitored by quality control.
- Select machining conditions which are recommended to produce long tool life and low rate of tool wear.
- Rigid tools and cutters, with the controlled edge geometry protected during handling, are desirable.
- Remove tools when the wear land reaches .005 to .008 inches. This is the point at which the wear land becomes visible to the naked eye.
- Cutting fluids should be fresh or well controlled and carefully and quickly removed from the workpiece when the operation is completed.
- Deburring of all machined edges is desirable.
- Parts stored for extended periods should be covered with a protective coating to prevent corrosion.
ABRASIVE PROCESSES GUIDELINES

- Low stress grinding techniques can reduce distortion and surface damage. Softer wheel grades, lower in-feeds and reduced grinding wheel speeds with chemically active cutting fluids are the principle elements of low stress grinding. Very low tensile and, in some cases, compressive residual stress conditions near the surface are attained.

- If low stress grinding is specified for the finishing operation, then conventional grinding can be used to within .010 inch of the finished size providing materials are not sensitive to cracking.

- Modifications of the low stress grinding procedures should not be attempted unless testing programs confirm that compromises can be tolerated.

- Conventional grinding conditions should not be used for grinding highly sensitive alloys such as the high strength steels (4340, D6ac), high temperature nickel (René 41, Inconel 718, L605) and cobalt alloys, titanium or molybdenum.

- Abusive grinding in martensitic steels can create untempered martensite zones and over-tempered zones below them, both of which can limit fatigue strength.

- Hand grinding of sensitive alloys should be discouraged, unless under very careful control.

- Controls for hand power sanders should be maintained.

- Abrasive cut-off frequently has a harsh deep surface effect and these altered layers should be removed.

- The heat affected zone from rough grinding can be much deeper than the surface discoloration. Microhardness traverses can generally detect the depth of HAZ alterations.

- Crack detection tests should be made to see that rough grinding does not create cracks. Surface cracks can propagate ahead of the finish grinding.

- Frequent dressing of the grinding wheels can reduce surface damage by keeping wheels open and sharp, thus helping to reduce temperatures at the wheel-workpiece interface.

- Cutting fluids and coolants should have a good and positively directed flow and be checked for their chemical action on the specific material being ground.

CHIP CUTTING PROCESSES GUIDELINES

- Plastic flow is frequently present and dull tools can produce laps, tears and roughness which can be initiating sites for fatigue failure.

- Sharp tools are essential in establishing surface integrity in turning, milling, and similar single point tool cutting processes.

- Maximum flank wear lands should be limited to .005-.008 inches.

- Form cutters tend to produce surface damage more readily than finishing tools generating a form.

- The heat from the passage of a cutting tool can produce metallurgical transformations—particularly so as the tools become more dull.

- Evidence of burning on the surface should initiate a check of depth of disturbance which can extend to .010 inch.

- Residual stresses from chip cutting tools are frequently compressive.

- Sharp drills should be used to help avoid serious surface layer alterations.

- Dwelling during drilling should be avoided; galling, torn or discolored surfaces should be cause for rejection or correction.

- Drill fixturing rigidity is desirable.

- Deburring is imperative on both entrance and exit of holes.

- Drilled and reamed holes should be chamfered on both exit and entrance.

- Reaming stock allowances should be controlled.

- A maximum number of holes per reamer should be specified and maintained despite visual appearance of reamer.

- Hand feeding of straight reamed holes should be avoided.

- Alignment, tool geometry and tool condition are important controls in hand reaming.

- Finish boring operations should maintain roughness limits and avoid laps and tears. Only very small wear lands can be tolerated with about .005 inch as a limit. One finish pass per cutting edge is a frequently set limit.

- Honing is an excellent finishing operation for developing surface integrity.

- Corrosion potential of some cutting fluids should be checked. Old fluids should be checked. Old fluids corrode more rapidly.
CHEMICAL PROCESSES GUIDELINES
(CHM – ELP)

- Chemical machining does not induce any significant stress in the machined surfaces.
- Some surface softening is frequently experienced from chemical processes.
- Selective etching, intergranular attack and pitting can result from off-standard conditions such as high temperature in the solutions, incomplete stirring, depleted or unbalanced solutions or contaminated solutions.
- Weld areas usually show a different rate of cutting.
- The metallurgical and heat treat state of the workpiece must be carefully controlled in order to secure repeatable results from chemical processes.
- Room temperature fatigue endurance strength generally is lower when compared to conventionally prepared low stress ground specimens.
- Surface roughness standards should be reassessed when applying CHM due to the different texture and absence of lay pattern.
- Surface roughness variations during processing can be a good indicator of changing processing conditions.
- Careful rinsing of the solutions from the finished workpiece is essential.
- The use of post treatments to add a compressively stressed surface layer may be desirable to enhance component fatigue strength.
- Steels and nickel base alloys, susceptible to hydrogen embrittlement, should have a post heat treatment of a few hours at a low temperature (375-400°F). It should be applied immediately after chemical processing.
- A test coupon for metallurgical evaluation should be made at least at 90-180 day intervals, or whenever the solutions are changed.

THERMAL PROCESSES GUIDELINES
(EDM – EBM – LBM)

- The surface texture is composed of a random array of cusps or pockets frequently with microcracks at the roughing level of processing.
- Surface roughness standards should be reassessed when using these processes due to the different texture and absence of lay patterns, as well as different methods of checking.
- Careful monitoring of the preselected operating parameters is necessary. Some older types of equipment do not maintain their initial setting throughout a long day or run.
- The heat affected zone (HAZ) produced by thermal material removal processes should be removed from highly stressed surfaces.
- The depth of the HAZ or recast structure on the surface is approximately proportional to the magnitude of the energy impinging on that surface. It is always present to some degree.
- The HAZ can induce a substantial tensile residual stress on the surface along with hardness variations dependent on degree of tempering.
- Fatigue strength is frequently severely reduced by the presence of the HAZ.
- Removal of the altered material zones (AMZ) may not be necessary if component or laboratory tests result in meeting design requirements.
- The prior condition of the workpiece is as important to generating surface quality as is the selection of operating parameters for the process.
- On thin components, high current densities may overheat the body of the workpiece.
- Thorough cleaning to remove dielectric fluids, beads and vapor residue is desirable.
ELECTROCHEMICAL PROCESSES GUIDELINES
(ECM, ECG, ES, STEM, ECT, ECH)

- Surface roughness standards should be reassessed when applying ECM due to the different textures and absence of lay pattern.
- Relentless process controls should be supplemented with periodic metallographic coupon checks from representative surfaces.
- Well controlled ECM does not induce any significant stresses on the surface.
- Selective etching, intergranular attack or pitting are evidences of less than optimum operating conditions or tooling practices. These conditions frequently occur on surfaces subjected to low current density in the presence of the electrolyte or in areas adjacent to the main electrode cutting face.
- The current density in the workpiece should be carefully planned to prevent overheating in the material.
- Localized overheating due to poor connections or short circuits should be individually and carefully examined for the extent of any damage. Removal of the surface discoloration on the surface is insufficient.
- High current densities are desirable in the cutting gap for good finishes and rapid metal removal.
- Contact between the electrolyte and workpiece without current flow should be minimized.
- Room temperature fatigue endurance strength is generally lower when compared to low stress conventionally ground specimens.
- The use of a post-ECMing shot peening treatment may be desirable to enhance component fatigue strength.
- The workpiece material heat treat state should be precisely known and controlled to assure the best repeatability of ECM surfaces.
- Careful rinsing of the electrolyte from the finished workpiece is essential.

SYSTEMATIC TESTING TECHNIQUES

Systematic metallurgical and mechanical testing programs for establishing and controlling surfaces are important. The minimum data set as described in pamphlet 1 is essentially a roughness, hardness and metallographic examination. It is quick and easy to perform and represents the minimum consideration for good product surface integrity. The standard data set (SDS) extends the information to include high cycle room temperature fatigue and residual stress. The extended data set covers special application-oriented data such as stress corrosion and low cycle fatigue.

QUALITY CONTROL AND NONDESTRUCTIVE TEST

Inspection practices should be reviewed and amplified to meet high surface quality requirements. There is no single test that assures surface integrity and the number of nondestructive tests available are limited.

Relentless monitoring of process conditions can be supplemented by coupon checks using the minimum data set measurements. More elaborate measurements with X-ray diffraction for residual stress and scanning electron microscope for microcracks are available.

Comparison of current results during production with standard sets of photo-micrographs that display both the “standard” and “off-standard” conditions to be expected are helpful. The growing data accumulations in surface integrity encyclopedias are useful. The U.S. Air Force Machinability Data Center (AFMDC) in Cincinnati, Ohio, has the most extensive collection of this information.

SPECIFICATIONS

Several companies now have special specifications for processing to secure the best surface integrity. These are very helpful to the vendors for guidance and to quality control for measurement. The call-out of these special specifications should be used with care and only used for those portions or surfaces of a component part deemed critical, or costs will rise unnecessarily.
REFERENCES AND GENERAL INFORMATION


SOURCES FOR FURTHER INFORMATION

1. Air Force Machinability Data Center (AFMDC), 3980 Rosslyn Dr., Cincinnati, Ohio 45209. Phone (513) 271-9510, Supervisor technical inquiries.


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