MANUFACTURING PROCESSES EFFECTS ON SURFACE INTEGRITY

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Categorization of processes has revealed a pattern based on energy classifications. The prime energy mode involved in a process was used to place it under one of four headings:

- Mechanical – including hydraulic
- Electrical – including magnetic
- Chemical – including metallurgical
- Thermal – including beams

There are usually several energy modes in evidence during a material removal process. The dominant mode is selected.

The energetic analysis of manufacturing processes has been examined extensively. The understanding of a process can be substantially increased if all of the energy modes are considered. The application of energy in whatever form has an impact on the raw workpiece that will contribute to its progress, or lack of it, towards the objective of producing a useful finished piece. The sequence of the application of energy changes the properties or dimensions of the workpiece with time. The value, process or manufacturing engineer directs his attention to finding the least costly routing from the initial to the final state of the workpiece. The analysis of all applied energies and their complete disposition will aid materially in the selection of the best route and bring much clearer understanding of the process involved.
MANUFACTURING TRENDS

With the increasing toughness of the newer materials, an increasing use is being made in the aerospace industry of the emerging nontraditional processes. The more conventional, generally mechanical, material removal processes experience shorter tool life with these materials. The tools dull more quickly and the wider wear lands result in tears, laps or similar mechanical distortions in the surface. The thermal cutting processes like EDM will show a heat affected zone (HAZ) or recast layers. Chemical selective etching or absorption can be experienced in the chemically-oriented processes.

The “modern” manufacturing engineer needs to be acquainted with these varieties of effects in order to select the best process to produce a given component. The engineer also needs to be familiar with all the altered material zones (AMZ) described in pamphlet 1.

INDICATORS OF NEED FOR SURFACE INTEGRITY EMPHASIS

While specific surface integrity process planning and controls should be applied only to critical surfaces of components (in contrast to general notes, e.g., “apply all over”), there are some situations or indicators that decree that a careful analysis for need be made. Some of these are:

- Use of special, high strength or sensitive materials
- Designs requiring more complete utilization of material properties
- Very thin wall designs
- Desires for extra long service life
- Surfaces with a high effect on product safety or reliability
- Distortion during production
- Cracking in processing or service
- New or unusual conditions of environment, stress, or temperature
- Damage or faults from accidents occurring during processing.

The entire sequence of processes used to produce a component part must be considered when assessing the component integrity. Each process will have its individual impact but the cumulative effect can be vastly altered by changing the sequence of process application.

CONVENTIONAL MECHANICAL MATERIAL REMOVAL (CGS – CML – CTR – CDR)

Conventional mechanical material removal processes have been used so long that it is easy to forget that they are characterized by mechanical deformation from the passage of the point of the cutter over the surface. Sometimes this passage is so swift (or the tool point so dull) that substantial heat is generated. The long familiarity with grinding “burns” is one example of heat affected zones (HAZ) from mechanical processes. It can occur on CML and CDR also. A regular lay texture in the surface characterizes mechanical processes (except for abrasive or grinding processes). Laps and tears in the surface are also common as the tools become dull.

PLASTIC DEFORMATION .0025 INCH DEEP FROM DRILLING OF INCONEL 718

AMZ FROM PASSAGE OF SUCCESSIVE TEETH OF MILLING CUTTER (250X)

MARTENSITE FROM AMZ ON MILLING OF 4340 Q&T, 50 R, WITH DULL CUTTER (.0005 INCH DEEP). ENLARGED VIEW OF ABOVE.
CHEMICAL MATERIAL REMOVAL PROCESSES (CHM – ELP)

Chemical machining produces an unstressed surface layer that repeats the previous surface texture and geometry. Some slight roughening of very smooth surfaces occurs; however, a smoothening of rougher surfaces occurs, particularly when the electrical assist of ELP is used. Selective etching and IGA can occur with poor or uncontrolled processing conditions. Some surface softening is frequent.

NONTRADITIONAL MECHANICAL MATERIAL REMOVAL PROCESSES (USM – AJM)

The multiple micro scale impacts of grit particles in USM erodes the workpiece and leaves a light but uniform compressive layer on the surface. A slight roughening occurs with a texture having no regular pattern. AJM secures material removal by the repeated passage of a fluid (sometimes loaded with abrasive particles) over or through the workpiece. Good fixtures are required to prevent erosion in undesired areas. Little or no disturbed material zone occurs because of the slow rate of removal.
THERMAL MATERIAL REMOVAL PROCESSES
(EDM — EBM — LBM)

Thermal processes always involve a heat-affected area on the surface. The magnitude depends primarily on the energy density impinging on the surface and the thermal characteristics of the workpiece material. The texture is random, and can exhibit splatter, recast, cracked or spalled material. Finishing or gentle operating parameters, when very carefully controlled, can minimize these effects. Thermal stresses, generally tensile, are present as microhardness variations.

ELECTRICAL MATERIAL REMOVAL PROCESSES
(EDM — ECG — STEM — ES)

The electrochemical dissolution of the workpiece surface leaves it in an unstressed state and when correctly selected operating conditions are carefully controlled, an unblemished surface will result (see page 10 of pamphlet 1'). When uncontrolled, IGA, selective etch and excessive roughness will occur. The large currents involved dictate extra attention to connections, over-current protection and the effects on adjacent areas from stray currents. Hydraulic forces and flow rates are considerable. Turbulent flow, free from cavitation, retains the usual very smooth untextured surface. The strong chemical reactions can result in asperities on the surface due to selective machining. Low current densities tend to promote selective etching and IGA.
POST TREATMENT PROCESSING

Finishing operations or post treatments to improve finishes or properties have long been used in manufacturing. Polishing, tumbling, burnishing are frequently used to decrease the roughness. These processes also add a compressive layer that aids fatigue-limited components. The greater awareness of processing effects has resulted in more deliberate use of special treatments such as shot peening to deliberately add a compressive layer to chemically or electrochemically produced surfaces. Likewise, special heat treatments can relieve the tensile layers from mechanically or thermally-produced surfaces. Rolling and extrusion honing will aid in finish improvement.

The emphasis must be in carefully designing the operation sequences so that the desired effects will appear in the finished workpiece. The effects are not necessarily additive or subtractive, particularly with the newer nonlinear processes.

NECESSITY FOR PROCESS CONTROL

The desire for improved surface quality is reflected in increased emphasis on inspection methods; particularly, nondestructive ones. Unfortunately, these are limited at the present time. It is necessary to fall back on carefully designed processes with precisely set operating parameters. Once these are set, qualified and the results checked, the unrelenting discipline of manufacturing management in maintaining them is essential. Spot checks and test coupon checks are helpful but the implacable insistence upon quality control the first time is mandatory. This is equally true for conventional or nontraditional processes.

GUIDELINES – ENCYCLOPEDIAS – SPECIFICATIONS

There is a dearth of good comparative data on the surface integrity effects on various process-material combinations. The best compilation currently is in the USAF/MATF Program MMP721-B. In the absence of data, general guidelines have been prepared for several processes. It must be recognized that these are general or starting recommendations only. Experience indicates that these practices lead to increased surface integrity. However, for highly critical or highly stressed surfaces, there is as yet no substitute for individual specific evaluations.

The greater care and control necessary to assure the highest surface quality generally will result in increased manufacturing costs or reduced productivity. This is appropriate where higher integrity, greater component integrity or improved safety is desired. Surface integrity is one of the essential ingredients to component integrity. The indiscriminate application of restraints, removal of AMZ’s or use of excessive finishing requirements, however, will unnecessarily increase costs. The opposite will avoid costs. Thus, for the maximum productivity, surface integrity standards should be applied only on those surfaces deemed critical from a stress or application need. A mechanism whereby the design engineer can call for the correct level of surface integrity consideration on a specific surface is being prepared by the General Electric Company, Cincinnati, Ohio. The planned surface integrity specifications will be supplemented by specific processing instructions. The specification and recommended practice documents will provide the design and process engineer with the tools he needs to correctly assess the impact of the process on surface integrity. It is desirable to back up these practices with adequate, specific, comparative data on materials of current interest.

General Electric is collecting and collating all of the surface integrity data that has been generated in a surface integrity encyclopedia. Additions to this collection are sought by the writers of these pamphlets and the information now collected is available to GE engineers. Metcut Research Associates of Cincinnati, Ohio have collected even more of this type of data for the AFMDC.
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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