PAMPHLET 1

INTRODUCTION TO SURFACE INTEGRITY

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Guy Bellows, Senior Manufacturing Engineer –
Advanced Manufacturing Process Engineering

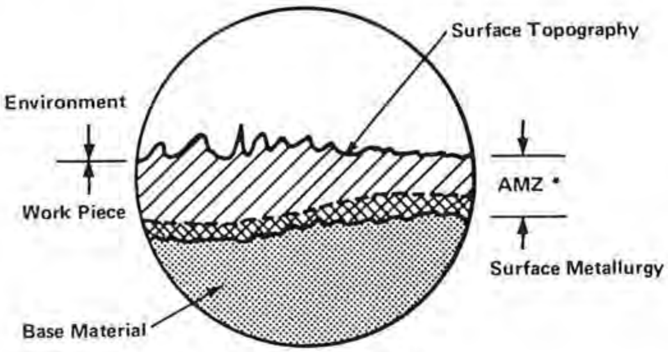
Dean N. Tishler, Engineer –
Material & Process Technology Laboratories

GENERAL ELECTRIC

AIRCRAFT ENGINE GROUP
CINCINNATI, OHIO 45215

DEFINITIONS

Surface integrity is the sum of all of the elements that describe all the conditions existing on or at the surface of a piece of finished hardware. Surface integrity has two aspects. The first is *surface topography* which describes the roughness, lay or texture of the outermost layer of the workpiece; i.e., its interface with the environment. The second is *surface metallurgy* which describes the nature of the altered layers below the surface with respect to the base or matrix material. It is the assessment of the impact of manufacturing processes on the properties of the workpiece material.



SIMULATED SECTION

GLOSSARY

* (See R67FPD260A for full set of acronyms)

AMZ	Altered Material Zone
CGS	Conventional Surface Grinding
CHM	Chemical Machining
CML	Conventional Milling
ECM	Electrochemical Machining
EDM	Electrical Discharge Machining
EDS	Extended Data Set
HCF	High Cycle Fatigue
HT	Heat Treatment
LBM	Laser Beam Machining
LCF	Low Cycle Fatigue
MDS	Minimum Data Set
SDS	Standard Data Set
SPE	Shot Peening
USM	Ultrasonic Machining

BACKGROUND

Surface integrity is a relatively new term introduced by Dr. M. Field ar Dr. J. Kahles of Metcut Research Associates at the 1964 Tripartite Tec nical Coordinating Symposium. The effect of grinding on residual stress metals has more than a decade of history. The above symposium marke the beginning of an effort to understand and document all of the surfa effects and the material properties for a larger variety of material remov processes—both traditional and nontraditional. The increasing use EDM, ECM, LBM, and other nontraditional processes with their unusu operating parameters has also accelerated interest in surface integrity.

Surface integrity is defined by Dr. Kahles as, "The unimpaired enhanced surface condition or properties of a material resulting from controlled manufacturing process". In a broad sense, the concern is fo surface quality. Surface integrity has two ingredients—those that relate t the surface topography and those that relate to the characterist immediately below the surface, i.e., surface metallurgy.

MATERIAL PROPERTIES

These pamphlets are primarily associated with the impact of the mar ufacturing process on the material properties. It is equally important t know the effect of the state of the material being presented fc processing: *Pamphlet 2*[1] illustrates one such case in the ECMing c Inconel 718. The high cycle fatigue data also shows some of th variations in endurance fatigue strength when aging follows machining machining in the solution treated and aged state. The material state is a important to surface integrity as the specific process operating parameters

SURFACE TOPOGRAPHY

Surface topography is concerned with the geometry of the outermo layer of the workpiece, its texture and its interface with the environmen These features have been well expressed for some time in ANSI Standa B46.1-1962, (GE Co.—Standard FPD-STD-18H1). In surface topograph roughness height from an average center line is frequently described t the AA (arithmetic average) microinch readings.

SURFACE METALLURGY

Surface metallurgy, the second ingredient in surface integrity, is concerned primarily with the host of effects a process has below the visible surface. The subsurface characteristics occur in various layers or zones. The subsurface altered material zones (AMZ) can be as simple as a stressed condition different from that in the body of the material or as complex as a grain structure change interlaced with intergranular attack (IGA). While undisturbed subsurface conditions are known, they are the exception. Changes can be caused by chemical, thermal, electrical, or mechanical energy and affect both the physical and the metallurgical properties of the material. The subsurface altered material zones can be grouped by their principal energy modes as follows:

Mechanical:	Plastic deformations
	Tears and laps
	Hardness alterations
	Cracks (macroscopic & microscopic)
	Residual stress
	Processing inclusions introduced
	Fatigue strength changes
Metallurgical:	Transformation of phases
	Grain size and shape
	Precipitate size and distribution
	Foreign inclusions in material
	Twinning
	Recrystallization
Chemical:	Intergranular attack (IGA)
	Intergranular corrosion (IGC)
	Intergranular oxidation (IGO)
	Contamination
	Embrittlement
	Pits or selective etch
	Corrosion
	Stress corrosion
Thermal:	Heat affected zone (HAZ)
	Recast or redeposited material
	Resolidified material
Electrical:	Conductivity change
	Magnetic change

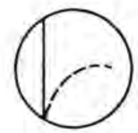
AMZ's DEFINED

CRACKS

Cracks are fissures in materials discernible with the unaided eye or with 10X or less magnification. The microcracks are only discernible at the greater magnification.

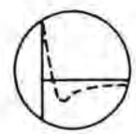
PLASTIC DEFORMATION

Microstructural changes, generally including elongation of grain structure and increased hardness, caused by exceeding the yield point of the material.



HARDNESS ALTERNATION

Changes in hardness of surface layers as a result of heat, mechanical working or chemical change during processing.



RESIDUAL STRESSES

Those stresses which are present in a material after all external forces (or thermal gradients, or external energy) have been removed.

METALLURGICAL TRANSFORMATIONS

These include resolidified layers, redeposited material, chemical reaction, depletion, grain structure change, or recrystallization as a result of external influences.

RECRYSTALLIZATION

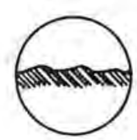
The formation of a new, strain-free grain or crystal structure from that existing in the material prior to processing usually as a result of plastic deformation and subsequent heating.

INTERGRANULAR ATTACK (IGA)

A form of in-process corrosion or attack in which preferential reactions are concentrated at the network of grain boundaries usually in the form of sharp notches or discontinuities.

SELECTIVE ETCH

A form of in-process corrosion or attack in which preferential reactions are concentrated within and through the grains or concentrated on certain constituents in the base material.



HEAT AFFECTED ZONE (HAZ)

That portion of a material not melted yet subjected to sufficient thermal energy to contain microstructure alterations.

INCREASING CONCERN FOR SURFACE INTEGRITY

The ever-increasing strength capabilities of the new aerospace materials has been accompanied by an increase in sensitivity to processing variables. The concern for surface integrity is the reflection of concern for component integrity and can be summarized in this listing:

- Thinner sections are more prevalent
- More sensitive and difficult alloys are being employed
- Higher stress levels are usual
- Designs are closer to material limits and capabilities
- Reliability requirements are more stringent
- Longevity requirements are increasing
- Awareness that there is a significant depth of impact of processes on materials is increasing.

MANUFACTURING TRENDS

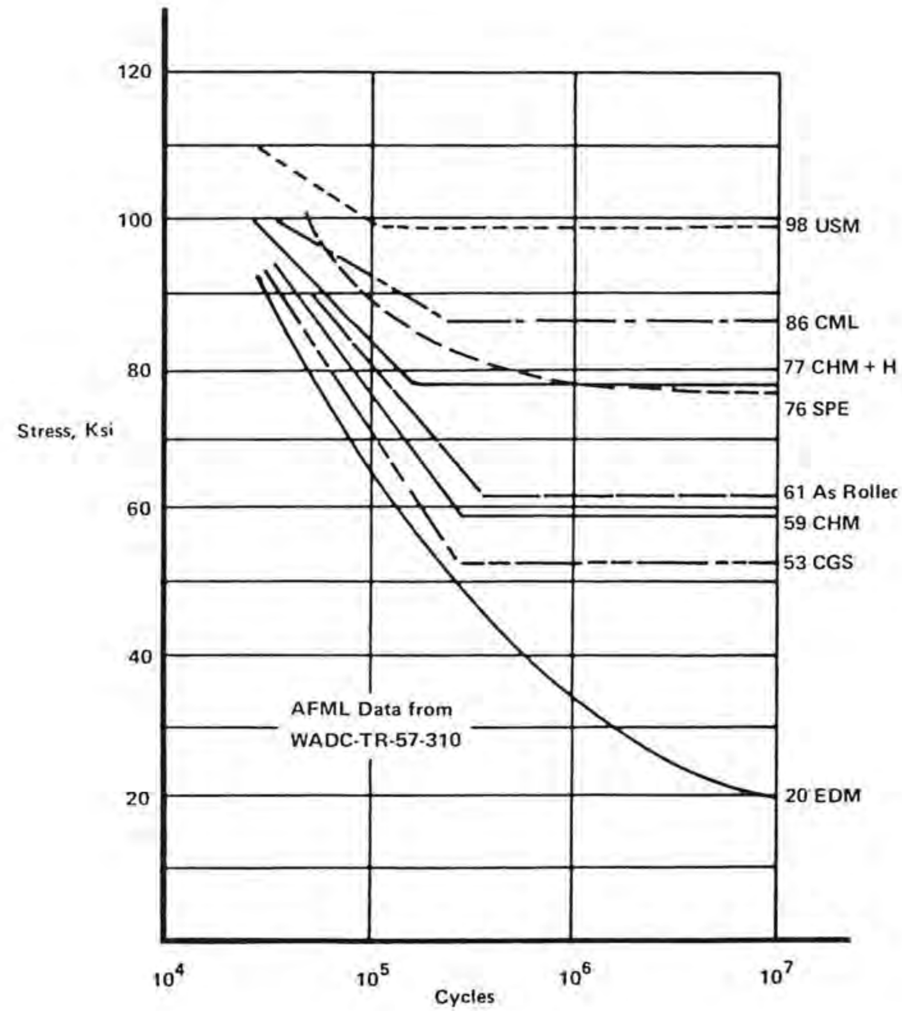
With the increased strength of materials has come an increased difficulty in machining them. Some of the new nickel based alloys have only 5-10 percent of the machinability rating of more conventional alloys. Fortunately, new cutting tool materials, more machine power and the advent of the electrical and other nontraditional material removal processes has enabled manufacturers to process these tougher materials.

The principal causes for the surface alterations that have been found in material removal operations are:

- High temperatures or high thermal gradients
- Mechanical working beyond the limit of plastic deformation
- Chemical reactions and subsequent absorption into the nacent machined surface.

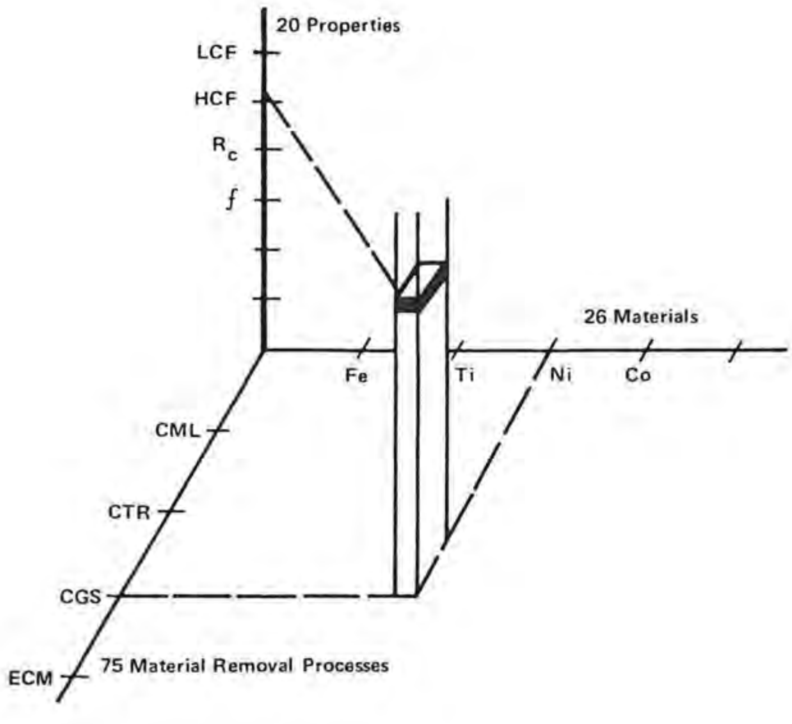
RANGE OF PROCESS IMPACT

The range of process impact can be illustrated by the S/N curves for A110 Titanium. With dynamic loading a limiting factor in many designs, it is essential to carefully consider the process used, its control at the level of processing intensity planned and carefully control the state of the material presented for processing. Each level of each process has a distinctive impact on the particular state of the material being processed. The process material "situation" has its own unique "fingerprint" left on the surface integrity.



SURFACE INTEGRITY DOMAIN

To obtain good process understanding and thereby achieve the best quality control, it is necessary to know the effects produced by various processing energy levels. We are interested in the gentle or finishing level as well as the roughing, abusive or off-standard level. Similarily, the state of the material—either hard or soft—is important. Thus, the surface integrity domain consists of the assessment of the material properties for a specific state of a material and for a specific level of the process. These data provide the evidence for definition of the manufacturing leeway.



SURFACE INTEGRITY "SITUATION"

- Particular *state* of a specific *material*
- Specific *process* operating *level*
- Assessment of individual *property*.

SURFACE INTEGRITY EVALUATION TECHNIQUES

At this point in time, definitive and complete sets of collated data specific process and material combinations are quite rare. A concei effort is being made by the USAF on their MMP721-8[2] program to col a few sets of comprehensive data. The General Electric Compan collecting surface integrity data in a separate encyclopedia.

Three types of surface integrity evaluation programs have been develo to provide three increasingly deep levels of study. The MDS data inclu the basic surface topography that is normal in assessing a machi surface and some of the metallurgical measurements. The SDS giv measure of the impact on material properties and is considered the b data set for correlation and comparisons. The EDS carries the in tigations even deeper and includes specialized and environment related effects.

The three levels are outlined as follows:

MINIMUM DATA SET, OR SURFACE METALLOGRAPHY (MDS)

- Surface roughness and texture or lay (photos and profile traces)
  - Macrocracks
- Microhardness profile or map
- Microsection metallurgical assessment (1000X preferred)
  - Microstructure transformation
  - Microcracks
  - Foreign or processing inclusions
  - IGA, HAZ, Selective etch, etc
  - Scanning electron microscope (SEM) photos (20, 200, 10 2000X preferred)

STANDARD DATA SET (SDS)

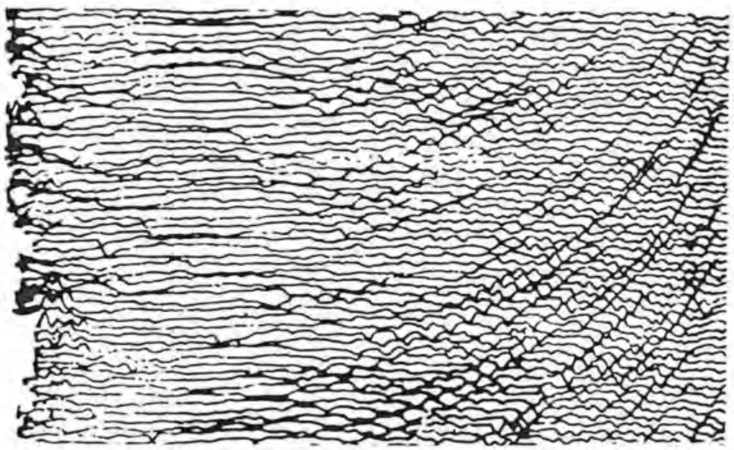
- Minimum data set
- Residual stress profile
- Fatigue strength (screening tests at room temp)

EXTENDED DATA SET (EDS)

- Standard data set
- Stress corrosion tests
- Fatigue strength (design data)
- Other specially selected tests.

SURFACE FINISH EVALUATION

The usual method for measuring surface roughness is with a small radius probe that traces a line on the surface and measures the amplitude of the roughness from a center line. The arithmetic average (AA) reading is expressed in microinches. Only one line (with a relatively large probe) is measured and the significant spot can be smaller and in other areas. Attempts are being made to expand these measurement capabilities as illustrated in this microtopographic map of a milled surface.



MICROTOPOGRAPHIC MAP OF MILLED SURFACE

METALLOGRAPHIC TECHNIQUES

One of the most informative and valuable tools for surface integrity evaluation is cross-section metallography. To be useful, however, it is necessary to take special care that good edge retention techniques are used. Project MMP721-8[2] reports on this need and outlines one method that has been found to be satisfactory. The mounting technique must not contaminate the surface or alter it, but it must have appropriate hardness and must cling closely so that edge breakdown does not occur during polishing. A plating on the surface (sometimes suggested) must not be used, particularly when evaluating electrochemical processes. The risk of contaminated observations is too great. The General Electric Company, Cincinnati, Ohio, has prepared special specifications for this type of metallography.

UNBLEMISHED SURFACE INTEGRITY

When the process-material match has been well selected and the operatic and material well controlled, an excellent unblemished surface can obtained on most materials, thus yielding the best component integr for dynamic loading or stress corrosive environments.

UNBLEMISHED SURFACE
(ECM of Udimet 500)

BENEFITS FROM SURFACE INTEGRITY CONTROL

The benefits that can accrue from surface integrity are:

- A better understanding of the process and process control limits
- Cost avoidance by use of surface integrity practices only where requir
- A reduction in scrap or rework incidents (do it right the first time)
- Better quality control
- Producibility/machinability data enhanced by surface integrity limits
- More valid value analysis
- Better definition of manufacturing leeways
- Guidance to advanced process design or application.

REFERENCES AND GENERAL INFORMATION

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2. "Surface Integrity of Machined Structural Components" – Koster, W.P.; Field, M.; Kahles, J.F. – Metcut Research Associates Inc. for USAF Project; MMP-721-8 Final Report AFML-TR-70-11, March 1970.

3. "The Surface Integrity of Machined & Ground High Strength Steels" – Field, M., and Kahles, J.F. – DMIC Report 210, pp. 54-77, Oct. 26-28, 1964.

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8. "Machining of High Strength Steels with Emphasis on Surface Integrity" – Field, M.; Koster, W.P.; Kohls, J.B. et al. – Metcut Research Associates for USAF, AFMDC No. 70-1, 1970.

SOURCES FOR FURTHER INFORMATION

1. Air Force Machinability Data Center (AFMDC), 3980 Rosslyn Dr., Cincinnati, Ohio 45209. Phone (513) 271-9510, Supervisor technical inquiries.
2. Guy Bellows, Sr. Mfg. Engr., Advanced Mfg. Proc. Engineering, Evendale Plant, Mail drop E-70, GE Co., Cincinnati, Ohio 45215. Phone (513) 243-4976 or dial comm. 8-332-4976.
3. Dean N. Tishler, Engr. Material and Process Tech. Labs, Evendale Plant, Mail drop M-88, GE Co., Cincinnati, Ohio 45215. Phone (513) 243-6771 or dial comm. 8-332-6771.