NEW QUALITY CONTROL REQUIREMENTS
FOR SURFACE INTEGRITY

by

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INTRODUCTION

During the past several years, attention has been drawn sharply to matters of safety and reliability as a result of changing attitudes and trends in many sectors of our society. For example:

1. The law courts have handed down decisions which make it essential for manufacturers and distributors to reconsider their position on matters concerning product liability as applied to all types of consumer products and especially capital equipment, such as machine tools, which will be in a liability situation for many years.

2. The Department of Defense and the commercial airlines as well are calling for greater reliability and simultaneously specifying more critical aerospace component designs.

3. The automotive industry has been under pressure to increase safety and reliability as evidenced by extensive recall programs, safety car design programs, antipollution devices, and new type engines which almost certainly will incorporate more critically stressed components.

4. Ground transportation in the form of high speed trains and revolutionary type vehicles is receiving worldwide attention in industry and government. Key issues undoubtedly will include matters of safety and reliability.

5. Atomic power plants have already suffered from adverse experiences, and therefore increased precautions will be taken in materials and processes associated with plant design and construction.

6. The Occupational Safety and Health Act (OSHA) is being implemented so widely that all equipment used in industrial plants must be re-assessed from a safety and reliability standpoint.

Concerns for increased safety and reliability relative to areas noted above have already initiated many new research and development planning efforts.
One of these was sponsored by the National Materials Advisory Board (NMAB) of the National Research Council on "Testing for Prediction of Material Performance in Components and Structures." Conclusion Number 3 on page 3-2 of this excellent report states:

"Conclusion:
In the course of design evolution, design or manufacturing modifications are sometimes introduced which affect performance life deduced from the original predictive tests which were run to verify design. Service performance failure is often observed to be associated with the alteration of the verified design's materials or processes without revalidation utilizing the applicable predictive tests of the original design process.

"Recommendation:
Changes in materials and/or processes after initial predictive testing shall only be made after design reverification, repeating the applicable predictive tests employed for the original verification and reanalyzing the applicable data gathered as in the original verification."

With reference to the above valid conclusion, it is important to recognize that most manufacturing personnel, including design and manufacturing engineers, metallurgists, and quality control engineers, are not sufficiently aware of some of the serious variations in mechanical properties which occur as a result of variations in our current production practices. In order to achieve reliability and safety in a component being machined or ground, it will be necessary to specify manufacturing parameters in much more detail than has been the custom even in our most progressive manufacturing plants.

A program which has provided considerable perspective concerning the problems industry is facing in achieving order of magnitude improvements

* Numbers in parentheses indicate references.
in product quality is the Surface Integrity Program sponsored by the Manufacturing Technology Division of the Air Force Materials Laboratory. In relationship to various interests in increasing the quality assurance of structural materials (the subject of this meeting), surface integrity studies have revealed some important data for consideration by anyone seriously interested in planning for the enhancement of safety and reliability. The principal purpose of this paper, therefore, is to present data which will support the following conclusions:

1. Many surface alterations produced by various material removal processes have a detrimental influence on the mechanical properties and are not detectable by equipment presently used for nondestructive testing as a final inspection method.

2. As a result of (1) above, it is absolutely essential at this time to rely upon in-process control procedures in order to develop structural integrity. It should be emphasized that suitable manufacturing methods can be established by using accepted testing and inspection practices, none of which are suitable, however, as NDT methods under production conditions in the shop.

**TYPICAL SURFACE ALTERATIONS NOT DETECTABLE BY NDT**

Figures 1 through 5 are examples of a few of the types of surface alterations which are not detectable by nondestructive testing equipment; appropriate descriptions accompany each figure. These surface conditions are typical of those created during material removal and other types of manufacturing processes and are the types of defects which cause the lowering of fatigue strength as illustrated in Figures 6 and 8. These charts show examples of wide variations in fatigue strength as a function of the type of material removal process used and also as a function of the specific parameters selected for a particular material removal process. Extensive additional data for other materials and processes may be found in References 2, 3 and 4.
From Figure 6, several important conclusions can be reached, probably the most important of which is that conventional grinding often shows great tendencies to act abusively toward a large variety of alloys used for production of critical parts. This confirms suspicions held in the aerospace industry for many years relative to the grinding of structural materials. On the other hand, gentle grinding (sometimes called "low stress" grinding) does provide excellent fatigue strength and when applied in production has been shown to eliminate cracking of very sensitive alloys. Gentle or low stress grinding conditions are described in detail in References 2 and 3. In general, they are established in production by simultaneously reducing grinding wheel speeds, lowering downfeed or infeed rates, using softer grinding wheels, and applying very active grinding oils rather than water soluble oils or emulsions. For operations such as turning, milling, drilling, etc., gentle material removal conditions are set up by using very sharp tools and using machining parameters which yield long tool life.

With reference to in-process control, low stress grinding has been shown to be an extremely reliable finishing process and one which is capable of producing very high quality surfaces. It has been employed in large-scale production operations to eliminate cracking of cast and wrought nickel base high temperature alloys used for blades in aircraft engine and electric power generation equipment. Figure 7(5) shows zyglo verification of the quality of surface produced by low stress grinding. The zyglo indications in Figure 7a, 7b and 7c reveal the presence of cracks, voids, and other surface defects caused by less than optimum grinding conditions.

Figure 8 provides some very interesting data with reference to fatigue strength of a widely used aerospace nickel base high temperature alloy. The alloy is
very prone toward damage in conventional grinding but, as noted earlier, it responds well when low stress grinding parameters are used. EDM processing drops fatigue strength sharply to a level of 22,000 psi both in roughing and finishing operations. During the finish operation, the recast layer produced was only .0001 in. to .0002 in. thick. For critically stressed applications, it is often necessary to remove the EDM surface layer by means of conventional machining operations, such as grinding, reaming, and honing. It is possible to restore the fatigue strength of an EDM surface by shot peening, as shown in Figure 8. A word of caution is in order, for it remains to be proved whether shot peening will provide a similar restoration of properties in production parts in service.

Engineers have frequently regarded electrochemical machining (ECM) as an operation which would minimize surface alterations. Most alloys show lower fatigue strength after ECM. Referring to Figure 8, Inconel 718, for example, showed a lowering from 60,000 psi for low stress grinding to 39,000 psi after ECM. It is customary practice in industry to shot peen after ECM on critical surfaces. The data in Figure 8 confirm the advisability of this practice on both electropolished (ELP) and ECM surfaces.

Based upon Metcut's surface integrity experience gained as a result of controlled testing programs and application experience in relation to production problems, it appears both essential and feasible to rely upon in-process control to improve the quality of manufactured products. By contrast, some of the final inspection procedures currently being used are often not applicable because they lack sensitivity to isolate the types of small detrimental alterations shown in Figures 1 through 5.
Surface Finish
Frequently, design and manufacturing engineers specify surface finish requirements for control of quality. The accepted standard for Surface Texture in the U.S. is ANSI B46.1. From experience gained to date, it appears that industry and government should reassess carefully the role of surface finish in design and manufacture of structural components. From surface integrity data developed to date, it appears that for structural components having a surface finish in a range of 10–125 microinches AA, surface finish cannot itself be used as a measure of or for control of surface integrity as evaluated by fatigue testing. Until additional much needed data are made available, manufacturers of critical components are encouraged to develop experimental programs for the purpose of opening up surface finish requirements, thereby reducing costs.

Figure 9 shows data upon which the above comments were made. These data show that for three different classes of materials tested, even though fine finishes were developed, the endurance limit was not increased. Only when gentle grinding conditions were employed was some improvement noted with fine finishes and even then the improvement was disproportionately small. It should be noted, however, that close dimensional tolerances cannot be specified without considering surface finish. In addition, surface finish is of considerable importance in the design, manufacture, and service performance of mating surfaces such as in bearings, cams, gears, etc.

Engineering Design Data
The fatigue data shown in Figures 6, 8 and 9 provide informative data on the endurance limits associated with various types of processing. This set of data, typical of a much larger set already available, raises thought-provoking questions
in relationship to design data. These data suggest the urgent need for a requirement to develop handbook data for important engineering materials for all commonly used processes for finishing the surfaces of critical parts. Such data could be incorporated into the "Aerospace Structural Materials Handbook" (7). At present, some data are already available from the Manufacturing Technology Division's Surface Integrity Program for inclusion in future supplements of the above handbook. Engineers cannot be expected to design highly stressed parts for structural purposes without initially factoring in the selection of specific manufacturing processes and control of specific manufacturing parameters for all critical parts.

In-Process Specifications

Earlier in this paper it was stated that in-process control can be and has been used successfully for manufacturing purposes in lieu of final inspection practices. Success of in-process control seems to be based upon the intelligent structuring of a control system which includes at least: 1) Setting up a systematic metallurgical and mechanical testing program for materials and processes for which data are not available. With regard to this recommendation, it should be emphasized that there is no difficulty in identifying surface alterations and measuring their influence, but this requires metallurgical sectioning for microscopic examination. As noted earlier in this paper, identification of surface defects is difficult when NDT conditions are requisite. 2) Writing and publishing in-process specifications. 3) Developing educational programs to acquaint personnel with surface integrity data and new quality control requirements.


ABUSIVE GRIND 4340, 50Rc 1000X

THE THIN WHITE MARTENSITIC LAYER IN THE ABOVE PHOTO-MICROGRAPH IS OFTEN FOUND IN THE SURFACES OF HARDENED ALLOY STEELS AFTER GRINDING. IT HAS BEEN FOUND THAT EVEN ISOLATED PATCHES OF UNTEMPERED OR OVERTEMPERED MARTENSITE AS THIN AS .002 IN. CAN REDUCE FATIGUE STRENGTH OF HIGH STRENGTH STEELS AS MUCH AS 35% TO 40%.
MACHINING OPERATIONS SUCH AS TURNING, DRILLING, MILLING, ETC., ESPECIALLY UNDER POOR MACHINING CONDITIONS, ARE PRONE TO PRODUCING SURFACES WITH A BUILT-UP EDGE. THIS PHOTOMICROGRAPH SHOWS THAT PORTION OF THE BUILT-UP EDGE WHICH WAS LEFT ON THE WORKPIECE. FRACTURE ANALYSES OF FAILED PARTS HAVE SHOWN THAT CRACKS ASSOCIATED WITH THE BUILT-UP EDGE HAVE SERVED AS ORIGINS OF THE FRACTURE.
CRACK-LIKE CREVICES, AS SHOWN IN THE ABOVE SURFACE, ARE COMMONLY FOUND IN DRILLED AND REAMED HOLES. THE SECTION SHOWN IS A BURR ON THE WORKPIECE SURFACE. BURRS HAVE BEEN SHOWN TO BE RESPONSIBLE FOR APPRECIABLE REDUCTION OF FATIGUE STRENGTH IN STEEL AND TITANIUM ALLOYS.
NOTE SHOULD BE TAKEN OF THE THIN RECAST LAYER APPROXIMATELY 0.001-0.002 IN. THICK. SUCH THIN LAYERS ARE AS DETRIMENTAL AS THOSE WHICH ARE TEN TIMES THICKER AND HAVE BEEN SHOWN TO REDUCE FATIGUE STRENGTH OFTEN AS MUCH AS 30% TO 70% IN HIGH STRENGTH AND THERMAL RESISTANT MATERIALS.
The above photomicrograph shows a surface having a pronounced tendency toward intergranular attack during an ECM process. Small defects, such as shown, are difficult to detect but they are detrimental and can be avoided through the use of proper in-process control of ECM conditions.
SUMMARY OF HIGH CYCLE FATIGUE RESPONSE: SURFACE GRINDING

ENDURANCE LIMIT, KSI
$10^7$ CYCLES FULLY REVERSED BENDING

Figure 6
ZYGLO INDICATIONS ON CAST NICKEL BASE ALLOY
RESULTING FROM DIFFERENCES IN GRINDING PRACTICE

Figure 7
SUMMARY OF HIGH CYCLE FATIGUE BEHAVIOR OF INCONEL 718 (SOLUTION TREATED AND AGED, 44 R_c)
SUMMARY OF FATIGUE STRENGTHS - SURFACE FINISH

ENDURANCE LIMIT, KSI
$10^7$ CYCLES FULLY REVERSED BENDING

Figure 9