Abstract

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MICROMETERING AND PERFORMANCE IMPACT OF SURFACE INTEGRITY ON PRODUCT DESIGN

SOCIETY OF MANUFACTURING ENGINEERS
DEARBORN, MICHIGAN 48128
20501 FORD ROAD
1975 INTERNATIONAL CONGRESS ON MANUFACTURING TECHNOLOGY, MAY 1975
EXPERIMENTAL SATELLITE INCIDENTS, SURFACE SATELLITE INCIDENTS
ANALYZE...

TECHNICAL PAPER
Critical designs, increased safety and reliability requirements, product liability trends, and the new OSHA standards have focused greater attention on surface integrity analysis. This paper describes the impact of newly developed surface integrity data, especially fatigue, on problems relating to quality control in the manufacture of critical components. General and specific recommendations are presented for initiation of cooperative programs with the objective of developing the large body of mechanical properties data required for quality assurance purposes and to make such data available in appropriate engineering design manuals. Limitations of present nondestructive testing methods for detecting surface alterations in final inspection are noted, leading to the recommendation for in-process controls. Combining of primary and secondary processing methods is suggested as a means for offsetting detrimental surface effects produced by primary processing methods.

INTRODUCTION

This International Conference on Surface Technology has focused sharply on the integrity of surfaces as measured by mechanical properties of materials and as demonstrated by the performance of critical components in service. During this meeting, substantial data have been presented which verify that many of our manufacturing methods require extensive improvement in order to meet our present and future quality assurance requirements.

Pressures which have drawn attention to the need for greater safety and reliability in manufactured products have come from various sectors of our society:

1. The law courts have handed down decisions which make it essential for manufacturers as well as the distributors of their products to give serious consideration to manufacturing procedures as they affect product liability. Product liability problems have multiplied in relationship to all types of consumer products and especially capital equipment, such as machine tools, etc., which remain in a liability situation for many years as a result of long-term usage.

2. The Department of Defense is calling for greater reliability and simultaneously specifying more critical component designs in all types of aerospace, ground and underwater vehicles.
3. The commercial airlines are calling for even greater reliability because of the extensive use of higher speed aircraft having passenger loads as high as 350 or more per plane. With the advent of the SST, requirements to control product integrity will be even more demanding.

4. The automotive industry has been under pressure to increase safety and reliability as evidenced by extensive recall programs and safety car design programs.

5. Ground transportation in the form of high speed trains and revolutionary type vehicles is receiving worldwide attention from industry and government. Key issues will most certainly include matters of safety and reliability, many of which will relate directly to manufacturing practices.

6. Nuclear power plants have already suffered from adverse experiences, and therefore increased precautions are and will continue to be taken in selection and control of materials and processes associated with plant design and construction.

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

Concern for improvement in the prediction of material performance has already attracted attention of groups such as the National Materials Advisory Board (NMAB) of the National Research Council. Conclusion Nos. 1, 3, and 4 on pages 3.1 and 3.2 of NMAB's excellent report on "Testing for Prediction of Material Performance in Components and Structures" are strongly supported by the surface integrity data which have been brought to our attention at this meeting:

"Conclusion No. 1

Users have paid insufficient attention to the need for test information which would more fully characterize the performance of materials in components and structures due to the secondary role accorded materials in procurement specifications. This applies to both requirements and evaluations."

"Conclusion No. 3

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."

"Conclusion No. 4

Failures of materials in components and systems have been observed where the failure appears to result from a lack of understanding of and failure to provide for the physical processes involved. This has precluded the development of adequate predictive tests."

Practical experience in implementing surface integrity data has demonstrated that one of the most significant causes of the conditions identified in Conclusion Nos. 1, 3, and 4 above stems from a lack of awareness on the part of top management, design engineers, metallurgists, manufacturing engineers, etc., of the many surface alterations which can occur during manufacturing and how seriously they influence the performance of components in service. This lack of awareness is not surprising, for even many design engineers and metallurgists are not aware of the high temperatures, the plastic deformation, and the chemical reactions which are taking place at the tool/workpiece interface nor is the manufacturing engineer trained in-depth to appreciate many of the important subtleties of material science and of mechanical testing. In light of new quality assurance requirements, this situation need not and indeed cannot continue.

From recent surface integrity data which have been made available including substantial quantities at this meeting--it is possible to make strong recommendations for action by users, the manufacturing industries, technical societies, and government. This, in fact, is the specific purpose of this paper. References 2 to 5 contain data which have established the basis for the recommendations which follow. It should be emphasized that these same data have been substantiated and highly supportive in the solution of critical and costly industry failure studies.

Following are some of the more important general and specific recommendations which we believe will be helpful toward improving safety and reliability of manufactured components.

GENERAL RECOMMENDATION

In relationship to the manufacture of critical items, the users who are demanding increased quality assurance, the manufacturing industries, technical societies and government all must make a careful assessment of the surface integrity of components and take appropriate action. Extensive cooperation will be needed to develop and assemble the large body of specific data which will be required in order to achieve a high level of quality assurance. In addition, the competitive feature which is so characteristic of a cost and production oriented industry environment requires modification. Surface integrity data must be widely disseminated and shared among competitors in order to avoid structural failures which may lead to loss of life and property.

-653-

-654-
SPECIFIC CONCLUSIONS AND RECOMMENDATIONS

The following specific conclusions and recommendations certainly do not comprise all of those which can be drawn from the many fine papers at this meeting, but they are typical and certainly significant enough to warrant serious attention on the part of the manufacturing community.

1. Mechanical property data derived from surface integrity studies sponsored by the Manufacturing Technology Division of the Air Force Materials Laboratory have verified that a large spread exists in mechanical properties as a function of the type of manufacturing process used and the specific parameters selected for any given process. (2, 3, 4) Figure 1 is typical of many data sets which have already been developed. This figure illustrates wide variations in fatigue strength as a function of the manner in which grinding is performed. Likewise, Figure 2 demonstrates the endurance limit variations in a single material such as Inconel 718, a nickel base high temperature alloy widely used in the manufacture of aerospace components. It should be noted that the endurance limit of Inconel 718 varies from 22,000 to 78,000 psi depending upon which of the 14 processes is selected.

Accordingly, it is recommended that new engineering design manuals be developed which list important engineering design properties as a function of commonly used manufacturing processes. It is important to note that data for specific mechanical design properties must be developed for each combination of specific material and specific manufacturing method. Such extensive programs will require substantial government funding as well as willing cooperation from a large sector of industry to share data which have already been produced either with private or government funds. While such a task is a substantial one, it is not insurmountable, for it is possible on a logical basis to limit the selection of specific materials associated with specific manufacturing processes. Wide dissemination of this type of engineering design information is required and can be achieved through broad-scope cooperative programs among the U.S. Government and its information analysis centers, industry, and technical societies.

2. Data are now available which show that many of the surface alterations which seriously impair engineering properties, such as fatigue, are so thin and so finely dispersed that they cannot be detected by any of the nondestructive testing methods which are now available. A few typical examples are shown in Figures 3, 4, 5, 6, and 7. Programs are necessary for the purpose of developing nondestructive testing (NDT) techniques which can be used for final inspection of components on a production basis.

At present, it is highly important to recognize the limitations of our present NDT methods so as not to set up conditions of false reliability. The problem of obtaining adequate NDT equipment is complicated by the fact that some materials show no surface alterations, even in destructive tests after processing, and are in fact predisposed to cracking in service as a result of the processing parameters used. This phenomenon has been encountered in certain high temperature alloys where cracking was not apparent until "green run" engine tests were performed.

3. In view of the conclusions reached in Item 2 above, it is essential, at least for the present, to develop refined methods of guaranteeing surface integrity through in-process control rather than by use of final inspection procedures. Applicable in-process control methods are too numerous to mention in detail, however, it would appear that new programs for developing automatic control of manufacturing parameters are needed and that the processing of components be certified by using control samples to be evaluated by destructive testing techniques.

4. At present, very few specifications exist for the control of the surface integrity of critically stressed components. Specifications should be developed on a broad base with action in this area being undertaken perhaps by a group such as the American Society for Testing and Materials and with subsequent implementation on an international basis. A sufficient number of surface integrity specifications have been written by companies such as Boeing, General Electric, McDonnell Douglas, Pratt & Whitney, and others so as to provide a nucleus for a specification-writing group.

5. Test data in Figure 1 suggest that conventional grinding should not be used for the finishing of components which are highly stressed or which are used in critical applications. This is especially true for materials such as titanium alloys and others which are sensitive to grinding. The parameters currently used in conventional grinding and the general lack of operator training and control in surface integrity will not provide finished parts which are assuredly free of detrimental surface alterations.

6. The test data in Figure 1 show clearly the high degree of surface integrity which can be achieved with gentle (low stress) grinding. It is recommended that this process be evaluated for broad application in the finishing of critical components, especially those made from sensitive materials. Figure 8 shows the successful application of gentle grinding to a sensitive cast nickel base high temperature alloy. For certain alloy systems, the data in Figure 8 indicate the possibility of using a penetrant method for final inspection assuming that a high
degree of in-process control was already established by use and control of the gentle or low stress grinding process and provided the alloy was sensitive to any deviations from low stress parameters as shown in Figure 8.

7. Strong objections to the use of gentle (low stress) grinding arise because of the reduced production rates and decreased grinding ratios as compared with conventional grinding. Actually, most conventional grinding operations produce surface alterations which, while detrimental, are still shallow enough to permit use of gentle grinding as a secondary or finishing process. In fact, many of our manufacturing processes should be reviewed for more extensive application of secondary processing in order to achieve high integrity. Examples are:

a. Conventional Grinding + Low Stress Grinding
b. High Speed Grinding + Low Stress Grinding
c. Electrical Discharge Machining (EDM) + Electrolytic Polishing, or Electrochemical Machining (ECM) + Shot Peening
d. EDM + Shot Peening
e. ECM + Shot Peening
f. Conventional Machining + Burnishing
g. Conventional Grinding + Honing

8. Data in Figure 9, supported by other information, have led to the conclusion that at least in the range of 10-125 microinches, surface roughness cannot of itself be used as a measure of surface integrity. Extensive efforts should be directed toward examining the role of surface finish in relationship to the mechanical properties and performance of all types of components. Evaluations which have already been made by some companies have yielded significant cost reductions through opening up of surface finish requirements in areas where they are nonsignificant. It appears that a cooperative effort will be required by industry, government and standards groups to properly define those component functions where surface roughness is an important requirement for maintaining component reliability in service.

9. Most manufacturing operations alter the residual stress patterns of the surface layer of a part. High residual stresses cause distortion, especially of fragile parts as demonstrated by extensive data collected by many investigators. Currently, attempts are being made to use rapid methods for measuring residual stress in order to measure surface quality. Work should be undertaken to examine critically the limitations of this type of nondestructive technique for guaranteeing quality.

10. Laboratory and field studies have demonstrated that certain materials are easily damaged during manufacturing. Also, certain processes inherently are not suitable for development of finished surfaces of critical parts even though they may be very effective for roughing and/or finishing of noncritical components. Specific identification of sensitive materials and sensitive processes must be made and linked closely with processing specifications and standards.

11. Earlier in this paper, the need for sharing of surface integrity data was indicated as being highly important in order to develop the large and extensive body of data required and also to eliminate the possibility of loss of life and property as a result of improper manufacturing processes. An important specific recommendation which should be considered is to develop cooperative procedures for collecting field data, analyzing it, and disseminating it.

12. Qualification of new processes and new materials offered by manufacturers for critical applications should include surface integrity data showing that meaningful mechanical properties are not impaired or that any surface alterations can be eliminated successfully by secondary processing methods. In recent years, new processes such as EDM, ECM, high speed grinding, laser machining, and others have come to the market unsupported for use in the manufacture of critical items, especially those made of highly sensitive materials.
REFERENCES


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

SUMMARY OF HIGH CYCLE FATIGUE RESPONSE: SURFACE GRINDING

Figure 1
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 .0002 IN. CAN REDUCE FATIGUE STRENGTH OF HIGH STRENGTH STEELS AS MUCH AS 35% TO 40%.

Figure 3
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.
HIGH STRENGTH AND THERMAL RESISTANT MATERIALS.
PATHOLE STRENGTH OFTEN AS MUCH AS 30% TO 70% IN
TEN TIMES THICKER AND HAVE BEEN SHOWN TO REDUCE
LAYERS AND AS DESTRUCTIVE AS THOSE WHICH ARE
APPROXIMATELY 0.0001 IN. THICK. SUCH THIN
NOTE SHOULD BE TAKEN ON THE THIN RECAST LAYER

6 R.

ELECTROCHEMICAL

MACHINING

DISCHARGE

TOOL STEEL

TYPE D2

1000X

MACROGRAPHY SHOWS A SURFACE HAVING A

MACHINING CAST REN 

1000X

AGED - 40R.

1000X

PARTICIPATED IN THE USE OF PROPER

CONDITIONS.

IN-PROCESS CONTROL OF ECD PROCESS.
Penetrant indications on cast nickel base alloy, low stress grind.

- Wheel dresser - coarse
- Grinding fluid - oil
- Wheel speed - 2000 SFM

- Wheel dresser - coarse
- Grinding fluid - oil
- Wheel speed - 4800 SFM

- Wheel dresser - fine
- Grinding fluid - oil
- Wheel speed - 4800 SFM

- Wheel dresser - fine
- Grinding fluid - oil
- Wheel speed - 6000 SFM