Modern Shot Peening Technology

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The subject of my presentation is "Modern Shot Peening Technology." Before I touch on the technical aspects of this topic, I would like to take the liberty to digress and request you kindly bear with me for a few moments. Having been in the shot peening field for the past 35 years, I consider myself to be one of the principals of the second generation of the so-called "American Shot Peening Fraternity." Looking back over these years, I am astounded that shot peening has generated so much interest during the last few years that three international conferences have taken place, all with extremely good turnout and interest. I'm sure that many of the original fathers of shot peening in the United States would join me today in taking great pride in the advancements that have been made in this industry. The original fathers to whom I refer, who to some extent were also my teachers, are John Almen, F. P. Zimmerli, J. Straub, Fred Landecker, Professor Henry Fuchs, O. J. Horger, Frank Sheppard and Herb Noble. Recognition also should go to Gerald Balcar for his contributions in the field of development and use of glass media for shot peening. In the area of ceramic media, recognition must be given SEPR, a French company which has done a great deal over the past few years to promote the use of ceramic beads. We also don't want to overlook CETIM in France, which pioneered and established the first international shot peening conference in Paris. Professor Henry Fuchs, the founder of Metal Improvement Company, who was one of my prime teachers and one of the first with whom I came in contact in the shot peening industry, today is still recognized as one of the top authorities in this field and is still quite active in new developments and innovations in the shot peening field.

I'm especially delighted to see the tremendous amount of activity and interest in shot peening emanating from the academic world. Students graduating today from universities majoring in metallurgy and engineering have a far better grasp of shot peening and its values as well as many of the other mechanical prestressing processes. With the everincreasing acceptability by industry of the benefits of shot peening, I would not at all be surprised if in the foreseeable future shot peening will be utilized to a far greater extent than it is today and will take its place as one of the many well accepted processes, such as heat treating and plating.

Shot peening is a very "forgiving" process. I refer to it as a "forgiving process" because in my experience I have seen many applications where less than optimum specifications were applied and yet the component in question still showed an improvement in fatigue properties. This, in my opinion, has been and still is a major stumbling block which has decelerated the growth and general acceptance of shot peening in the marketplace. It is this lack of repeatability that has prompted considerable caution on the part of engineers and metallurgists. It has only been in the past three years that industry has been forced to intensify its efforts to try to obtain optimum improvement through the use of shot peening rather than accepting "just an improvement." Today more and more highly stressed components designed for life enhancement conditions require careful scrutinization which necessitate almost flawless shot peening controls.

I believe that the days where shot peening was used strictly as a "fix" are past. This philosophy of optimum improvement and optimum controls in the use of the shot peening process has evolved because components today are subjected to higher stresses under far more severe conditions, and engineers are frank in admitting that the process if properly applied is one of the best, least expensive and most versatile available, involving the least amount of tooling and start-up costs. This thinking has strongly motivated the shot peening industry to devote a great deal more attention to establishing tighter controls, and major advancements and changes in methodology are being developed to assure engineers that all the variables in the process are controllable on a continuous basis. Within the past three to five years, all of us in the shot peening industry have uncovered a variety of questions which must be addressed in order to assure the end user that the process will give optimum improvement and also repeatability.

The first two international shot peening conferences which I attended in Paris and in Chicago covered both the practical and the theoretical aspects of shot peening and brought to light a great need for refinement of the process as well as a number of unanswered questions which we must all address. I have no doubt that as the industry continues to mature, solutions will be found to many of these unanswered questions, which will result in a greater respect for the process and greater advancements in the state of the art.

In my 35 years, I have been witness to numerous plateaus which I will cover in more detail in a few moments. As each plateau was reached, regardless whether it was in the area of media improvement, equipment modifications or application engineering, we in the shot peening field were quick to learn from one another and disseminated these new concepts to a hungry industry which was more than receptive and willing to utilize the new developments that came to their attention.

These are just a few of the highlights of my years of exposure in this industry which I wanted to share with you. It's been a very exciting and a very innovative period and I'm sure that many more milestones and plateaus will be reached in the years to come....

....and now for the subject "Modern Shot Peening Technology."

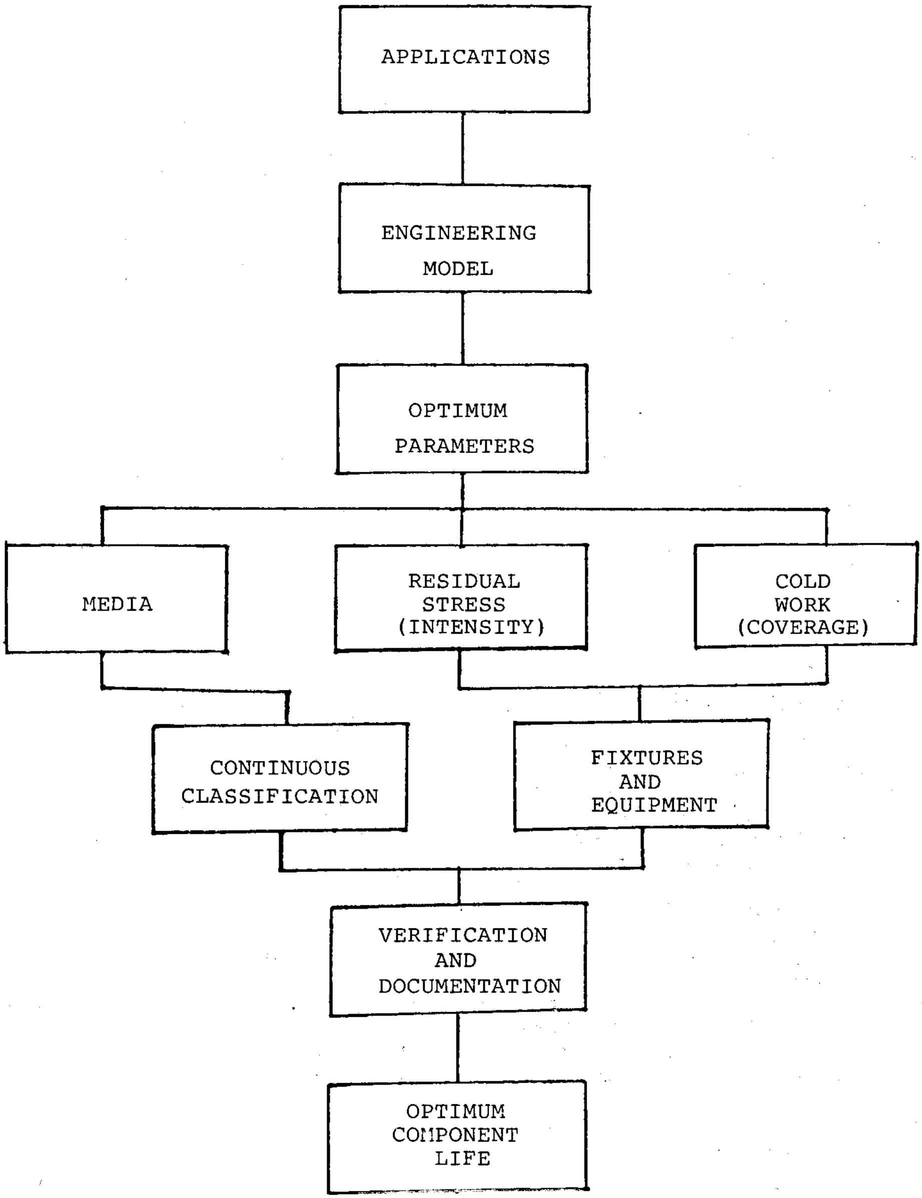

Fig. 1: Modern Shot Peening Technology

Figure 1 is an illustration of the direction being taken by current shot peening technology. Applications information such as material properties, load history and desired life can be entered into engineering models now under development for shot peening. The result of entering the applications information into the engineering models would be optimum shot peening parameters. Optimum shot peening parameters include media, residual stress (intensity) and cold work (coverage) specifications. These specifications will be closely controlled in the peening process by systems using continuous shot classification, fixtures (consisting of nozzle fixtures, Almen strip fixtures, actual part holding fixtures) and computer controlled shot peening equipment. Computer controlled shot peening equipment contains verification and documentation features to ensure process repeatability. With the ability to identify optimum shot peening parameters and to rigidly control the peening process available, designers can then utilize the full benefit of shot peening in the design of critical components for life enhancement purposes. Typical shot peening applications are listed in Figure 2: improvement in fatigue properties in virtually all metal alloys, retardation of certain forms of corrosion (such as stress corrosion cracking, intergranular corrosion and hydrogen assisted cracking), forming of metal parts such as wingskins, cold work of metal surfaces to improve wear characteristics and miscellaneous applications such as texturing, testing for adherence of coating, elimination of porosity, etc.

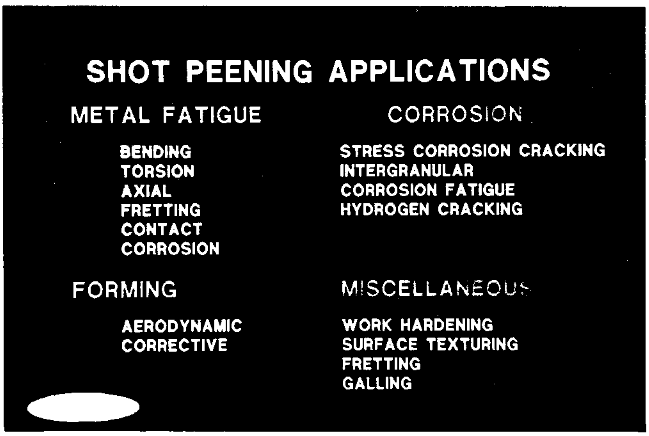

Fig. 2:

Traditionally, shot peening started out as a fix, whereby engineers having trouble with a component in service could improve the component life by shot peening. Next, peening began to be recognized and used as a safety factor. Designers would design their component for optimum life as best they could and then shot peen it for added protection or added life. With the advent of highly stressed exotic alloys, designers are pushed to new limits. They will be able to rely on shot peening to help meet the design requirements of their component. However, these new applications place a high technical demand on the shot peening process.

<u>MATERIAL PROPERTIES</u>

- Loading
- Environment
- Material Response to Peening

ENGINEERING
FORMULA

<u>OPTIMUM PARAMETERS</u>

- Media
- Residual Stress
- Depth
- Magnitude
- Cold Work
- Percent Coverage

<u>Fig. 3:</u>

The work currently being done on modeling the shot peening process is vital. Material properties, calculated and measured loads and the shot peening response of materials can be entered into developed engineering formulas (Figure 3). These formulas will yield optimum shot peening parameters such as type of media, media size, media hardness, desired residual stress depth, desired residual stress magnitude and desired amount of induced cold work. Initially, peening parameters were recommended through limited knowledge. As experience was generated in many applications, recommendations of optimum peening parameters were done through experience and data results. Now with the onset of shot peening models and engineering calculations, designers can determine optimum peening parameters using a sound technical engineering approach.

We can see in Figure 4 the progression of peening media advance from chilled iron shot used in the 1930's and 1940's to the introduction of cast steel shot in 1951. Stainless steel cut wire was introduced in 1957. In 1960 glass beads were first used for peening media. An advance took place in peening media in 1970 with the introduction of special hardness steel shot. The next peening media to be introduced was in 1981 when ceramic beads became available. In 1986 exotic media such as shot made from nickel base alloys were used for certain special applications.

MEDIA

Original	-	Chilled Iron
1951	-	Cast Steel
1957	-	Stainless Steel Cut Wire
1960	-	Glass Beads
1970	-	Special Hardness Cast Steel
1981	-	Ceramic Beads
1986	-	Exotic Metals

Fig. 4

Controls and media quality have also changed over the years. It started with virtually no control to the use of dust collectors to draw out very fine particles and dust. Then came the use of so-called "limited separators" which were designed to draw out more of the fine particles and strong enough to also draw out some of the smaller broken particles as well as the dust. This did not really do the job since larger broken particles whose weight was almost equal to a round particle still stayed in the machines. Now shot separation systems are utilized on new generation computer controlled peening machines which continuously separate the shot by both size and shape throughout the entire shot peening operation. These continuous classification systems have the capability to segregate multiple sizes simultaneously and are able to control the quality of the peening shot in the machine to well within current specifications.

RESIDUAL STRESS MEASUREMENT

- Almen Strip
- Valentine Recrystallization Method
- Strips of Actual Material
- Etching Technique
- Strain Gauge
- Dimple Diameter
- Blind Hold Drilling
- X-Ray Diffraction

Fig. 5

Advances in residual stress or intensity measurement are summarized in Figure 5. The Almen strip was invented back in the early 1940's and is still in use today to indicate the amount of energy transferred to the workpiece by the shot stream. In later years strips of the actual material being shot peened were used and then correlated to the Almen intensity method for indicating the energy transfer. K.B. Valentine in 1947 developed a method called Valentine recrystallization which was a measurement of cold work by taking a mild steel part, shot peening it under specific parameters, annealing, and then measuring the growth in grain structure which indicates the depth of cold work. Next came the etching technique to determine depth and magnitude of compressive stress. In the etching technique an actual strip of the material in question is shot peened under controlled specifications on both sides. Then thin layers are chemically etched off one side of the strip and measurements taken accordingly. Strain gauges were used at a later date to measure the amounts of stresses induced into the part. Dimple diameter technique was also used, but usually on softer materials such as aluminum, for the measurement of depth of compressive stress. This method correlated a direct relationship between the dimple diameter and depth in a one to one ratio. Then came the blind hole drilling technique for measuring the amount and depth of residual stress. Finally today, to a large extent, X-ray diffraction is used for measurement of residual stresses and their depth induced by shot peening. All of these techniques enabled engineers to know to a certain degree how much benefit they may be able to obtain from shot peening through knowledge of depth and magnitude of the residual stresses induced.

COLD WORK MEASUREMENT

- Visual Coverage
- Micro Hardness Tert
- X-Ray Diffraction
- Peenscan Coverage

Fig. 6

The measurement of cold work or coverage started with visual coverage using a 10-power magnifying glass or similar apparatus (Figure 6). Boroscopes are used for internal visual inspection to determine evidence of complete dimpling or indentation of the surface of the shot peened component. The method of visual inspection for coverage is extremely difficult, if not impossible, when using a media softer than the actual part being shot peened. Microhardness tests were used to measure the amount of cold work induced by shot peening and, finally, data gathered from X-ray diffraction measurements of residual stresses also give an indication of the amount of cold work induced by shot peening. Most recently a fluorescent tracer liquid technique was developed. This technique has been very useful in the verification of shot peening coverage. It is known as the Peenscan Process, whereby a part is coated with a special fluorescent tracer liquid and the liquid is removed during the peening process at a rate proportional to the shot peening coverage.

Controls of the peening process have gone through similar changes over the years. Initially, there were no peening setups and shot peening was done strictly on a manual basis. Next, multi-nozzle peening machines were developed and setup of those machines was done by an operator, on a manual basis, using a detailed process description or process sheet. With the advent of computer controlled shot peening equipment, permanent hard tooling has been used in the form of nozzle fixtures. The nozzle fixtures eliminate potential operator error in setup of the machine because they are locked in a preapproved location. Other recent computer controlled shot peening equipment uses robotic techniques whereby the angle and distance and target area of the nozzle is determined by the computer controlling the equipment and the peening is done in a robotic fashion.

PROCESS CONTROL

- Manual Peening
- Semi-Automatic Equipment
- Fully Automatic Equipment
- Numerical Controls
- Computer and Robotic Equipment

Fig. 7

In Figure 7 we can also follow the development of shot peening machinery over the years, starting with manual peening in its initial stages. Manual peening gave way to semi-automatic, or the batch method of peening equipment. Next came fully automated shot peening equipment where the process was set up and repeated under automatic conditions. Then came numerical controlled equipment in which the positions of the peening nozzles were directed and controlled by numerical control techniques. Numerical control was utilized mostly on components whose shape and configuration were difficult to automate in a standard type shot peening machine. Currently, computerized and robotic peening equipment is now available which includes positive controls over shot flow, air pressure, centrifugal wheel speed, part rotation or oscillation through the shot stream, running time and cycle time. This type of equipment can be hooked into multi-task computers which can run numerous pieces of equipment simultaneously. In addition to controlling the peening process, the computers can monitor the status of all critical parameters and document the fact that these parameters have been maintained within preapproved limits by the use of computer printouts.

VERIFICATION

- Visual/Audio Monitoring
- Actual Testing
- On-Stream Monitors
- Automatic Shut-Down

DOCUMENTATION

- Inspection Reports
- Certification
- Computer Print-out

Fig. 8

Figure 8 traces the progress of verification and documentation techniques over the years. Initially visual inspection or actual audio monitoring by the operators at the machine was the only method available. Actual testing via the use of Almen fixtures and Almen strips as well as residual stress measurements were then used to verify that the energy transferred to the workpiece by the process was correct and within acceptable specifications. Current computer controlled equipment now uses onstream sensors which monitor the status of the critical peening parameters during the operation of the machine. These onstream monitors send their data to the computers which evaluate the status of each critical parameter with respect to preprogrammed maximum and minimum limits. If either the maximum or the minimum limit is exceeded during operation, the computer shuts the machine down, remembers the point in the operation at which the shutdown occurred, signals to the operator the cause of the shutdown, and documents the event on the computer printout. Documentation has evolved over the years from reports of inspection personnel - to certifications - to computer printout. The computer printout is a detailed documentation of the status of the critical peening parameters recorded throughout the actual peening cycle.

Programs currently under development are summarized in Figure 9:

1 - Media.
We in the shot peening industry are working to develop new improved peening media which will give longer media life, im-

proved fracture mode and 100% removal of unacceptable particles. By improved fracture mode, we are looking at peening media which will not break down into sharp edge particles that will possibly damage the surface upon subsequent impact. The improved media would wear or break down in a fashion which would allow virtually 100% removal of unacceptable particles each time the shot passes through the machine.

2 - Engineering Models and Equations.
Currently being developed are material response equations which document and predict the response of specific materials to shot peening. These curves would be similar to the curves used for predicting the depth of compressive layer induced by peening as a result of the peening intensity. Also, optimum life equations are being developed to predict optimum fatigue characteristics from a particular application. Other areas of investigation are test procedures to verify that optimum life predictions have been made. This would be in the form of comparative fatigue testing techniques.

3 - Computer Controlled Shot Peening Equipment.
Computer controlled shot peening equipment is now a fact of the peening industry; but under current development are: improvements on computer controls of all critical peening parameters, improved monitoring systems with better accuracies and incorporation of statistical process control into the software of the computer controlled equipment. The monitoring systems and documentation used on the computer controlled equipment are readily adaptable to statistical process control charting. It is a matter only of incorporating the sampling techniques and the SPC charting into current software.

<u>CURRENT DEVELOPMENT PROGRAMS</u>

1. Media
   a. Improved Life
   b. Improved Fracture Mode
   c. 100% Removal Unacceptable Particles

2. Engineering
   a. Material Response Equations
   b. Optimum Life Equations
   c. Test Procedures to Verify Optimum Life

3. Computer Controlled Equipment
   a. Computer Control of All Critical Parameters
   b. Improved Monitoring Systems
   c. Statistical Process Control Incorporation into Software

<u>Fig. 9</u>

Future needs. As we look into the future for shot peening and its technology (Figure 10), we see the need for improved peening media, with improved life and improved fracture characteristics. We see the need for finalization of the engineering models and equations which will yield optimum peening parameters. We see the need for a nondestructive technique to measure the peening effect. (There is no nondestructive technique currently available to verify that shot peening has been done correctly.) We would all like to see such a technique come into being. And the last of the needs, and certainly not the least important, is the education of all industries on available peening technology. There are still people in many industries that don't know about shot peening or the benefits that can be achieved by shot peening. A good deal of education of the metalworking industry is still needed.

FUTURE NEEDS

1. Improved Media
2. Engineering Models/Equations
3. Nondestructive Test to Measure Residual Stress
4. Education of All Industries on Available Peening Technology

Fig. 10

The goal of any shot peening process must be optimum component life, no matter what the application. This can be accomplished with the use of engineering models which will yield optimum peening parameters and strict process controls through the utilization of computer controlled equipment with continuous shot classification and improved shot peening media. With these innovations in place, designers of fatigue critical and corrosion critical components will then be able to utilize the full benefit of the shot peening process in the design of their components.