THE CONTROL OF MANUAL SHOT PEENING

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ABSTRACT

The control of shot peening is paramount in ensuring that metal parts are correctly treated. The development of the control parameters, Almen Intensity and Coverage, and procedures necessary for the satisfactory manual shot peening of an aluminium alloy which required the introduction of a particular stress-depth distribution are described. Reference is made to the influence of Almen Intensity, Coverage, Shot size and Quality on the stress distribution, and techniques are suggested which could minimise the risk factors of 'operator integrity' and 'operator bias' inherent in all manual shot peening operations. The application of the control parameters to the standardising of different manual shot peening plants is described, and some effects of overpeening and the treatment of different aluminium alloys are discussed.

KEYWORDS

Residual Stresses, Peening, Stress Corrosion Cracking, Quality Assurance

INTRODUCTION

To obtain the optimum benefits of shot peening, it is essential that the process be closely controlled. The prime objective of controlled shot peening is to produce a compressively stressed layer in which the magnitude and uniformity of stress,and the depth of layer can be held constant within a component or between components. The control of the process becomes absolutely necessary when it is impossible or impracticable to inspect the stress distribution on a finished part i.e where it is considered time consuming to apply X-ray techniques or destructive to drill small blind holes in components. The required stress-depth distribution and surface coverage are in practice obtained by the relevant combination of operating variables.

The vast majority of peening operations are fully mechanised and the control of the process to achieve the correct values of Coverage and Intensity is carried out by controlling the machine parameters. However in some instances due to component size and/or shape it is necessary to employ shot peening treatments which require manual operations. The basic problems inherent in these so called manual operations are those of 'operator bias' and 'operator integrity', and these must be overcome to ensure that the job is done properly.

This paper describes the procedures adopted to develop the required shot peening treatment in terms of compressive stress versus depth, and discusses the particular problems associated with the control of manual shot peening and the precautions necessary to ensure that the part is adequately treated.

REQUIREMENTS OF SHOT PEENING TREATMENT

The material to be treated was an aluminium alloy in plate form of nominal composition Al-4½Zn-2½Mg, which had nominal mechanical properties of 0.2% Proof Stress, Ultimate Tensile Strength, and Elongation of 400 $MN.m^{-2}$, 460 $MN.m^{-2}$ and 12% respectively.

The requirement was to introduce a peening treatment for the prevention of stress corrosion in plate edges adjacent to welds. It was required that the compressive stress would be induced to such a depth to resist any damage such as wear, scouring or corrosion which would remove the benefit of peening. In particular the requirements were:-

Compressive residual stress at surface.
Compressive residual stress exceeding 1.0mm in depth.
Coverage of at least 98%.
A stress-depth distribution which is constant over the entire surface being treated.
Repeatability of the stress-depth distribution between components.
Repeatability of the stress-depth distribution at different factory locations.

Experimental stress analysis on plates peened with 1.2 mm diameter stainless steel shot, at a range of Intensities from 0.30 - 0.62 (mm) A, and from 50 to 150% Coverage was carried out (Birley, Morton, Alder, 1977). This revealed that the conditions required were met by peening within the Intensity range 0.5 - 0.6 (mm) A Almen. With the particular equipment being employed, this was achieved by the following operating conditions:- 4 bar air pressure, 20 mm stand off distance between nozzle and workpiece, 10 mm diameter nozzle and Normal incidence of blast. Complete Coverage could be achieved at a rate of area traverse of 1000 sq cm in 3.25 mins (3 mins per sq ft). Because of operator bias, which is discussed below, it does not necessarily follow that, in manual peening, a large area will be covered to the same degree in a proportionally longer time e.g 32.5 mins m^{-2}. This has been noted previously (Clarke, Birley 1978). As a means of reducing this, the workpiece may be artificially divided into small manageable units to assist the operator in achieving uniform coverage. The total peening time should be based on practice and not solely on the theoretical value.

BASIC PARAMETERS

General

A Process Schedule is required which records all the relevant information about the peening operation. This will include, amongst other items, all the variables of peening such as Intensity Range, shot size and material, the air or water pressure which influences the shot velocity, the duration of peening, the workpiece nozzle stand off distance, the angle of the nozzle with respect to the workpiece, and the nozzle diameter and shape.

After selecting the shot size and type the key parameters which control the peening process are the Almen Intensity and Coverage.

Almen Intensity and Saturation

The techniques for determining the Intensity are well known. The primary purpose of the Almen Strip is to measure the energy of the shot stream for process and quality control, but for this to be of validity it is necessary to ensure that the strip is saturated, and that this condition occurs within a reasonable peening time.

Saturation is the condition which exists in an Almen test strip when doubling the peening time causes a rise in the Intensity value of not more than 10%. See Fig 1. It corresponds to a condition where the test strip has a uniform distribution and consistent magnitude of the compressive residual stresses, and where Coverage is close to 100%. At saturation, the Intensity is a measure of the magnitude and depth of the compressive residual stress in the test piece, and higher impact energies will result in a higher stress level, and/or deeper penetration.

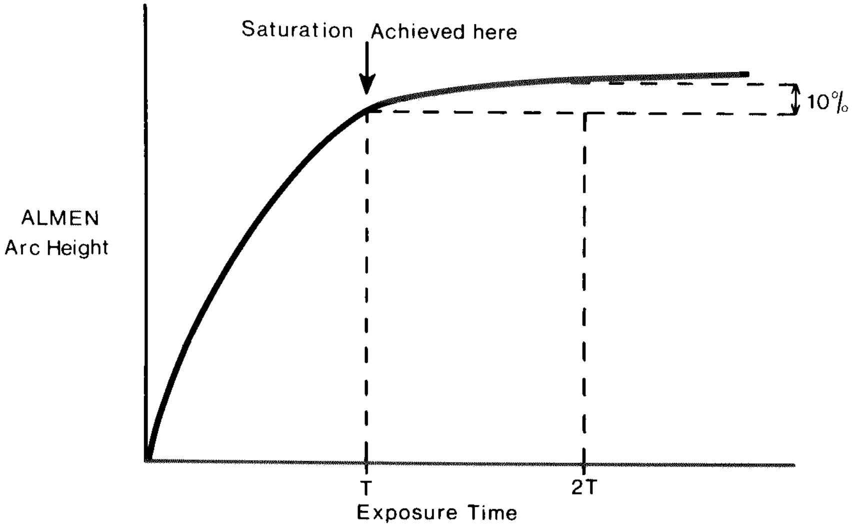

FIG.1 Saturation curve for peening

The Almen test strip is an artificial notion when the peening of metals of different hardnesses is being considered. Softer materials than the test strip will reach saturation and complete coverage earlier, and the reverse for harder materials. Because the purpose of peening components is to ensure that a uniform distribution and reproducible level of compressive residual stress is induced in the surface, it is absolutely paramount that saturation should be reached in the component being treated.

For materials of similar hardness to the test strip, the data obtained on test strips is applicable directly to the component. However, where marked differences in hardness between the component material and test strip exist some other method of determining the peening condition for obtaining saturation in the component is required. Several methods may be employed such as (i) applying a suitable multiplication factor (ii) the use of test strips manufactured from the component in place of standard Almen test strips and (iii) the determination in the component by visual estimation of the time to produce complete coverage. All methods are in use, and in the current application a combination of (i) and (iii) was used, and method (ii) was employed to verify the results since this method is probably the most accurate (Clarke, Birley, Owens, 1978).

Determination of Peening Time

In method (i), the data obtained during the establishment of the saturation plot is used directly for determination of the peening time but a factor dependent upon the hardness of the components is employed. Where the Almen test strip is mounted on a test fixture the area peened in a given time i.e the peening constant can be calculated.

$$\text{Peening Constant} = \frac{\text{Area of test strip}}{\text{Time to reach saturation}}$$

For metals of appreciably different hardness, a material factor is used for multiplying the basic time. This is derived from the test data by peening non-standard test strips in the component material to saturation under similar conditions to the standard Almen test strip.

$$\text{Material Factor} = \frac{\text{time to peen non-standard material strip to saturation}}{\text{time to peen standard strip to saturation.}}$$

Method (ii) removes the uncertainties of material factor by replacing the Almen test strips of comparable material as the components to be peened and the saturation point is determined.

Method (iii) employs visual coverage as the means of determining saturation and is dependent upon the premise that saturation corresponds to complete coverage. Using the established conditions a component is uniformly peened for a period of time less than that anticipated to be necessary e.g. one quarter of the estimated time. The surface of the component is examined visually and the coverage obtained is estimated. The component is then peened for a further similar period and a further estimate of the coverage is made. These operations are repeated until over 100% coverage is achieved. From a plot of the shot exposure time against coverage, the exposure to achieve 98% coverage is determined. Moreover, in order to eliminate any effects of variations in operator the shot exposure is increased by at least 20% i.e peen to give 120% coverage.

PROBLEMS WITH MANUAL OPERATIONS

In manual operations, rather than fully mechanized processes, there are two particular problems to overcome before one can be assured of achieving the correct values of Intensity and Coverage. These are Operator Bias and Integrity, and the effects of these on the major control parameters are discussed below.

Intensity Measurements

When an Almen test strip is attached to the workpiece in fully mechanised operations, the test strip achieves the same degree of treatment as the components, since the machine, when traversing the component, cannot distinguish between the two. However, in the case of manual operations the operator is aware of the Almen test strip and of its purpose as a process monitor and will ensure that the test strip is adequately treated. As a result, the Almen test strip will most probably receive favoured treatment such that when it indicates the required Intensity level, the part will be lower than than required. This is due to 'Operator Bias' and is a natural aspect of human behaviour. The problem may be overcome by having the Almen test strips located, not on the part, but on small test plates, typically 150 mm x 150 mm. This serves two purposes. One is that the Almen test strips comprise a significant part of this smaller test piece and therefore minimises the degree to which the operator can bias towards the test strips with respect to the bare material.Test strips are monitored periodically and this serves to check that the Intensity produced by the machine and shot variables is constant during the peening of components between checks.

Coverage

It is essential that a minimum of 98% Coverage is maintained over the entire treated surface. That is, there should be no holidays (or gaps) in the peening. This relies in manual peening, to a great extent on the 'Integrity' of the operator to maintain the nozzle at the required angle and stand-off distance, and to move it at a specified area traverse rate across the component such that the required level of coverage is achieved. However, after peening for the specified time required to achieve complete coverage at a given rate of traverse it will be found that uniform treatment has not been effected due to a natural bias to treat some locations preferentially to others e.g. areas adjacent to component edges or welds in preference to centres of larger areas of plate. Thus some areas will have more than 98% Coverage, but others will have holidays or gaps in the peening.

The problem can be minimised by specifying a traversing rate which equates to 120% Coverage i.e allowing 20% extra time for the coverage of that area. This will ensure that all areas will at least be fully covered. The actual tolerance of the material to accept more than 100% Coverage without showing overpeening effects can be determined by stress measurements and metallographic examination of a sample cross section. Complete Coverage (98%) should always be specified and visual inspection can then be employed to ensure freedom from holidays as for fully mechanised peening.

There is however a particular problem associated with multipeening operations both for the operator and for the inspector. Such operations may be required to prevent sub-assemblies cracking in storage prior to assembly into the main structure. The problem arises when welding these into the main frame since the welding removes the beneficial effect of peening (Birley 1981). Therefore further peening is required, but since the surface has a peened appearance, it is difficult to witness the operation i.e be assured that the operation has been done. This is very difficult but assistance can be given to the operator by means of witness coatings of dye. The workpiece is sprayed with a coating, and its subsequent removal ensures that successful peening has been achieved. This technique has been successfully employed on the alloys under consideration in this work (Clarke, Birley 1978) but it is recognised that specific dye coatings may well have to be developed for other peening conditions.

ASSESSMENT OF DIFFERENT PEENING PLANTS

It is not justifiable to expect identical behaviour on different peening machines with identical settings, and re-establishment of peening conditions will be necessary on changes of machines. Changes may occur for example due to the fact that air pressures in different plants may be measured at different locations or measuring gauges may differ with respect to calibration or accuracy. For example using the operating conditions previously established one plant was found to produce an Almen Intensity of 0.7 (mm) A.

Calibration of each plant is achieved by the determination of the particular specified operating parameters, on a particular plant, which are required to produce the specified Almen Intensity range of 0.5 - 0.6 (mm) A on saturation. Peened sample test plates of the Al-Zn-Mg alloy can then be subjected to stress measurement by the blind hole drilling technique (Owens, 1980) to confirm that the correct stress depth distribution has been achieved by the use of these conditions.

OVERPEENING

Overpeening is peening for too long or for too high an Intensity, which can result in the introduction of cracks in the surface of the metal. This results in a marked reduction in compressive stress at the surface and therefore the peening loses its effect. In addition, the cracks might propagate through the peened layer under favourable stress conditions.

Regarding treatment at too high an Intensity, it was shown (Birley, Morton, Alder 1977) that treatments between 0.3 and 0.62 (mm) A were satisfactory with respect to overpeening effects. With the equipment employed in this work, it is unlikely, that the Intensities will fall outside this range, and therefore there is no danger from overpeening (or underpeening) with respect to Intensity.

With respect to overpeening by time, it has already been stated that an operator may, because of bias, peen an area more than is required. Moreover, in multi-peening operations previously mentioned, it is necessary to peen an area which has already been treated.

A short experiment was carried out to assess the effects of overpeening. Four trial plates were given treatments in the range 0.5 - 0.62 (mm) A on saturation for Coverages of 100, 200, 300 and 400% respectively. These results, fully reported elsewhere (Birley, Owens and Clarke 1978) indicated that the mean compressive stress in the surface layer seemed to increase slightly with Coverage, and the extrapolated compressive stress at the surface decreased with Coverage. However, there was adequate protection provided by each treatment, and it was concluded that there is no real danger from overpeening (by time) within the range up to 400%.

TREATMENT OF DIFFERENT AL-ZN-MG ALLOY

Although the peening treatment described above is satisfactory for the Al-4$\frac{1}{2}$Zn-2$\frac{1}{2}$Mg alloy, it may not be quite so satisfactory on softer material e.g. Al-4Zn-2Mg heat treated to say 130 H_V, since it will relatively overpeen the softer alloy. Because shot penetrates deeper into the softer alloy, Coverage will be reached at an earlier point in time. An example of the stress-vs-depth curve for the softer alloy is shown in Fig 2, in which it is noted that the stress is relatively low at the surface, and the 'peak' of the curve occurs at a deeper level in the material than for the harder alloy. While this treatment is acceptable for the softer alloy, it is not the most optimum, this being achieved when the stress-vs-depth distribution shows both a 'peak' quite close to the surface, and a small surface drop-off in stress. It is essential therefore to evaluate separately the optimum parameters for each type of material to be treated.

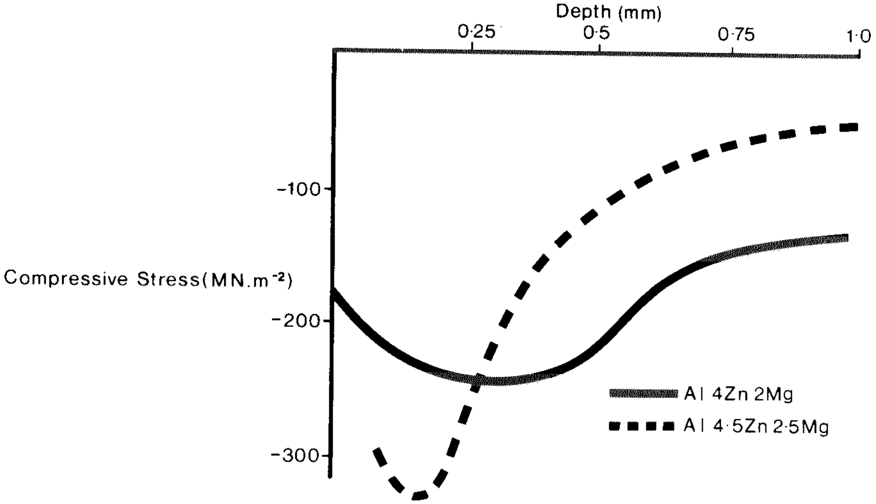

FIG.2 Stress-vs-depth curves for two Al-Zn-Mg alloys exhibiting different mechanical properties

CONCLUSIONS AND SUMMARY

Controlled shot peening can be achieved satisfactorily with manual operations.

Precautions must be taken to overcome the risk factors of operator bias and integrity.

Practical methods of achieving satisfactory manual peening have been described.

Provided all the precautionary measures described are taken, there is no danger from overpeening, in the ranges of Intensity and on the equipment employed in the current work.

The development of control parameters have been outlined. Because materials respond in different ways to the same peening treatment, it is essential to evaluate separately the individual optimum parameters for each material. This also applies to peening plants which are nominally similar.

REFERENCES

Birley, S.S, M.J.Morton and J.F.Alder (1977) Residual Stresses in Welded Joints and the Effects of Mechanical Surface Treatments Conference 'Residual Stresses in Welded Construction and their Effects', Welding Institute, London 185-193

Birley, S.S (1981) Shot Peening as a Stress Corrosion Preventive in Al-Zn-Mg welded joints First International Conference on Shot Peening, Paris
Clarke, D and S.S Birley (1978) Shot Peening Witness Engineering 956-957
Clarke, D, S.S.Birley and A.Owens (1978) The Application of Residual Stress Measurement in Welded Aluminium Alloy Sections Conference, British Society for Strain Measurement (B.S.S.M), Bradford.

Owens, A. (1980) Calibration of the Centre Hole Technique of Residual Stress Measurement B.S.S.M/I Prod.E.International Conference Birmingham