SHOT PEENING AS A STRESS CORROSION PREVENTIVE IN AL-ZN-MG WELDED JOINTS

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ABSTRACT

Residual stresses in unpeened welded joints are compared with stresses in similar joints which had been peened. Peening introduces a compressive stress-depth distribution which is independent of the distribution which existed prior to peening. The effects of the shot peening variables are briefly described and the stress distribution induced by shot peening is compared with other mechanical treatments such as needle peening, hammer peening, roto peening, roller burnishing, grit blasting and vibratory stress relieving, and with thermal stress relieving. Discussion is centred on the effect of these treatments as stress corrosion preventives in Al-Zn-Mg alloy plate edges, with reference to the effect of shot peening before, rather than after, welding.

KEYWORDS

Residual Stress, Shot Peening, Welding, Vibratory Stress Relieving, Thermal Stress Relieving, Aluminium Alloys, Stress Corrosion Cracking.

INTRODUCTION

Stress Corrosion Cracking (SCC) of welded Al-Zn-Mg fabrications is promoted by a unique combination of tensile stress, corrosive environment, and susceptible metallurgical structure. Some high strength alloys are so susceptible to SCC in the short transverse direction (edges) that it is unlikely that they can be rendered immune by heat treatment with the knowledge available at present. Moreover these alloys are prone to SCC in ambient air and it is therefore often impracticable to exclude the environment from the system: coatings only delay cracking. Therefore the only short term practicable approach is to reduce the level of tensile stress in the structure to below the threshold level. (This can approach zero in these alloys). This objective can be achieved reliably by the application of a mechanical surface treatment such as peening. Such a process however is an 'overkill' treatment since it introduces a compressive stress. It also has the advantage of being 'self-witnessing'. A further key advantage is that the depth of compressive stress can be controlled to cater for situations where surfaces could be subjected to wear, scouring, or corrosion which would tend to remove the protective treatment.

The purpose of this paper is to determine the depths of compressive layers produced by various mechanical surface treatments such as peening. The efficacy of these treatments are compared to thermal stress relieving and vibratory stress relieving (VSR) as stress corrosion preventives in Al-Zn-Mg plate edges. Some consideration is also given to whether peening should be carried out before, rather than after, welding.

The results of transverse stress versus depth measurements obtained on a welded cruciform joint, shown in Fig 1(a), both before and after welding are shown in Fig 1(b). Note that the stress-depth curve is similar to that induced into an annealed metal coupon given similar treatment: this is incorporated into Fig 1(b). It is seen that the stress-depth distribution resulting from peening is independent of the prior stress distribution. These results were obtained for needle peening (Bathgate, 1974) but similar results have been obtained for shot peening on a wide variety of joints in the author's laboratory. See Fig 2. These results are highly significant because it makes possible the comparison or evaluation of mechanical surface treatments by examination of annealed metal coupons rather than complex real joints; conversely one can ensure that, within the range of parameters considered in this work, that the stress distribution near the surface in a real welded joint will be the same as that in the annealed coupon, for a particular peening treatment (Birley, Morton, Alder, 1977).

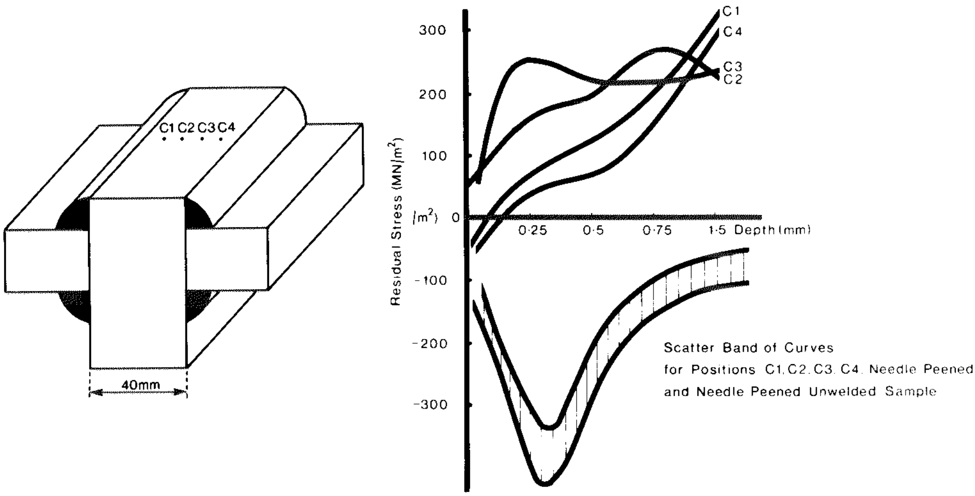

Fig 1(a) Cruciform Joint with measurement positions. Fig 1(b) Residual Stresses at positions C1, C2, C3, C4 unpeened, Residual Stresses at similar positions peened, and Residual Stress in annealed plate unwelded.

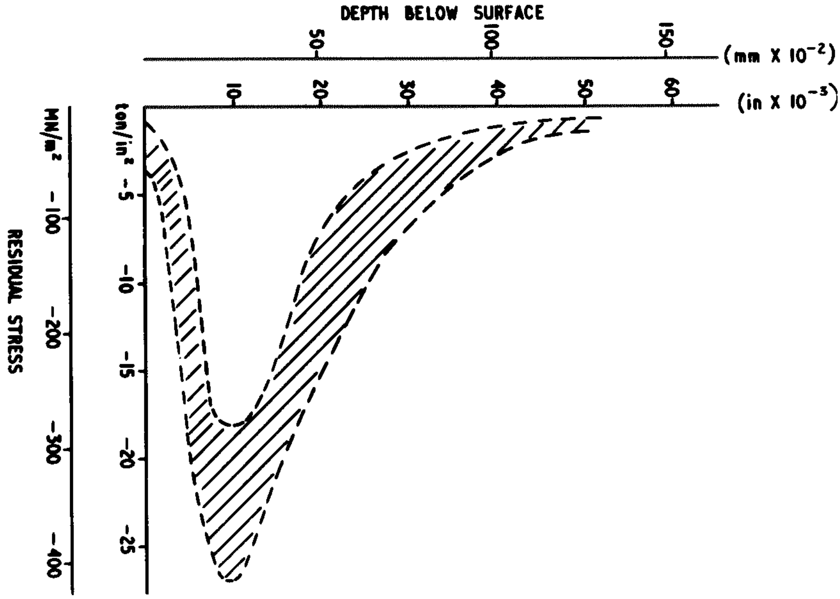

Fig.2 Residual Stress versus Depth curve for Shot Peening for a Variety of Joint Designs and for an Unwelded sample.

PARAMETERS OF CONTROLLED SHOT PEENING

The objective of controlled shot peening is to produce a compressively stressed surface layer so that the magnitude and uniformity of stress, and depth of layer, can be held constant over the whole of a component and between components. Control of the process becomes essential where it is impossible or impracticable to inspect the stress distribution on a finished part. There will be much discussion in this conference about control parameters, but it is sufficient to state here that only two control parameters, the Almen Intensity, and Coverage are required to ensure the introduction of a particular stress-depth layer. This pre-supposes that the shot size, type and material have already been selected, because for aluminium alloys in particular, this parameter significantly influences the depth of compressive layer produced.

MATERIAL TREATED AND STRESS MEASUREMENT METHODS

Material Treated

The material employed in the tests were wrought Al-4½Zn-2½Mg alloy plate having a 0.2% Proof Stress, and Ultimate Tensile Strength of approximately 400 and 460 $MN.m^{-2}$ respectively. All comparative tests were carried out on annealed coupons, except those to determine the effects of thermal stress relieving, VSR, and peening before welding, which were carried out on welded joints.

Stress Measurement Methods

Most of the stress measurements were carried out by the centre hole drilling technique. The use of this technique to determine the variations of residual stresses with depth is described by Owens, (1980). In the case of VSR assessment, surface measurements only were determined, using X-ray techniques.

SURFACE MECHANICAL TREATMENTS

General

There are many occasions where shot peening is not practicable, for example, when protecting very small areas, one-off components, difficult access areas, field applications, or when a fine surface finish is required. It was therefore necessary to assess alternative candidate treatements in terms of stress-depth distribution, as stress corrosion preventives.

Shot Peening

Samples were shot peened with 1.2 mm diameter stainless steel shot, at an Almen Intensity range of 0.50 - 0.51 mm A, and 120% Coverage.

Needle Peening

The needle peening of samples of plate edges was carried out using a needle gun (modified descaling tool) containing 3 or 4 mm diameter needles and using an air pressure of 6 bar. One sample was peened with the gun held normal to the surface being treated using 4 mm diameter needles until complete coverage was attained. Two other samples were peened with 3 mm or 4 mm diameter needles respectively for two minutes and complete coverage was attained in both cases. For these samples, the gun was inclined at approximately 30° to the surface normal to simulate the treatment of a plate edge within an aperture, where perpendicular application is not possible.

Hammer Peening

One sample was peened with a 12.5 mm diameter tool with an end radius of 6.25 mm, operating at 6 bar pressure, until complete coverage was obtained. This produced a surface similar in appearance to that of needle peening, but is particularly suited for treatment of small areas.

Roller Burnishing

A compressive stress was introduced into a 30 mm thick plate by increasing the diameter of an existing hole by 0.25 mm. This process produces a smooth surface finish and is useful for situations where close tolerances and smooth surfaces are required.

Roto Peening

Samples of plate measuring 30 mm x 100 mm were treated with double extended flaps containing 1 mm diameter balls. One sample was peened for 2 minutes at 3000 r.p.m, the second for 4 minutes. There are many variations of this process, which is particularly suitable for peening small holes.

Grit Blasting

This process is often employed for deforming the surface with relatively small indentors of irregular shape for descaling, roughening the surface prior to the application of protective coatings or for cosmetic effects. This treatment is usually applied in an uncontrolled manner, and the logical extension of grit blasting to a controlled process is that of peening. To assess grit blasting, coupons were treated using different sizes of grit, application times and angles of application. In all cases the surface was completely covered.

VIBRATORY AND THERMAL STRESS RELIEVING

General

Both these processes are not surface specific. They could, in fact, be regarded as 'volume' treatments because the whole fabricated structure can be treated, not only the susceptible edges. These treatments also differ from the peening treatments in that they are not self-witnessing.

Vibratory Stress Relieving (VSR)

Because VSR leaves no witness it has to be controlled in a manner different to that adopted for peening. The response of VSR is unique to the structure being treated, therefore, the treatment was applied to a large welded box, rather than a single joint. In order that stress measurements could be made in the same position both before and after VSR, a non-destructive technique (X-rays) was employed. The surface stresses only were determined as a function of distance from the weld, in a direction transverse to the weld.

The VSR treatment was carried out using a 3 phase AC equipment capable of oscillating at 0 to 110 Hz (100 Hz = 6000 r.p.m). The component was isolated from the ground on three 100 mm high anti-vibrator mounts positioned so as to give the minimum of damping of the amplitudes induced. A slow scan of 10 minutes was carried out to determine the descrete frequencies at which treatment was to take place. The frequencies were noted, and each was returned to and treated at resonance for 3000 cycles each. There is no historical data to give guidance for the VSR of the material, therefore the treatment had to be on the basis of judgement and intuition. After each condition had been treated a run-through of all the modes was given in the operating range 0 to 110 Hz. During the treatment amplitudes of up to 20 mm were observed and this was considered, at the time, adequate to seek response from the material. Four joints were subjected to stress measurement, but the results of one only are presented in this work, the one which gave the maximum response.

Thermal Stress Relief (TSR)

To assess the effect of TSR, cruciform joints of the type shown in Fig 1(a) were subjected to the following post weld ageing treatments:-

$150^{o}C$ for 8 hrs
$120^{o}C$ for 72 hrs
$90^{o}C$ for 8 hrs plus $150^{o}C$ for 8 hrs

These treatments were selected because they do not significantly reduce the mechanical properties to unacceptable levels. Previous work by the author, unpublished, employing X-rays, had demonstrated that no significant stress relief was obtained until temperatures of $250^{o}C$ - $300^{o}C$ were exceeded, or treatments were carried out for prolonged times at $180^{o}C$. The object of carrying out stress measurements by hole drilling was to confirm these results in the range of temperatures where post weld ageing is considered realistic i.e does not degrade the primary properties. Measurements were taken in the centre of the edges of the cruciforms.

COMPARISON OF TREATMENTS - RESULTS AND DISCUSSION

The results are presented in Figs 2 - 8.

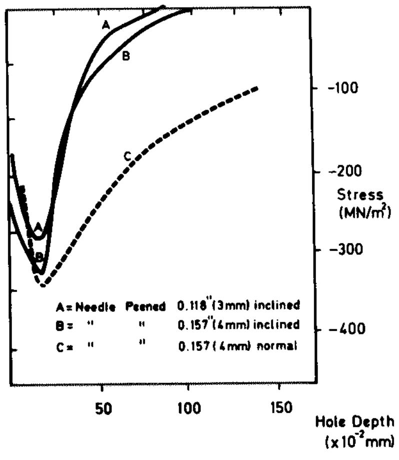

FIG.3 Residual Stress versus Depth curves for Needle Peening

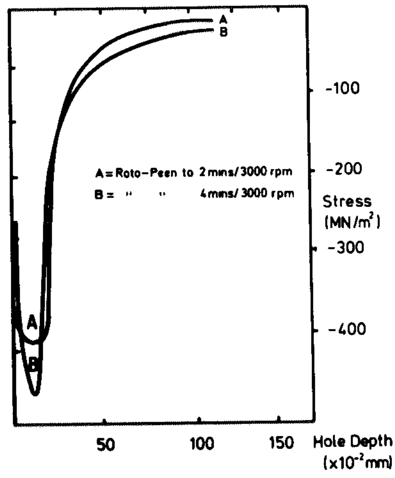

FIG.4 Residual Stress versus Depth curve for Roto Peening

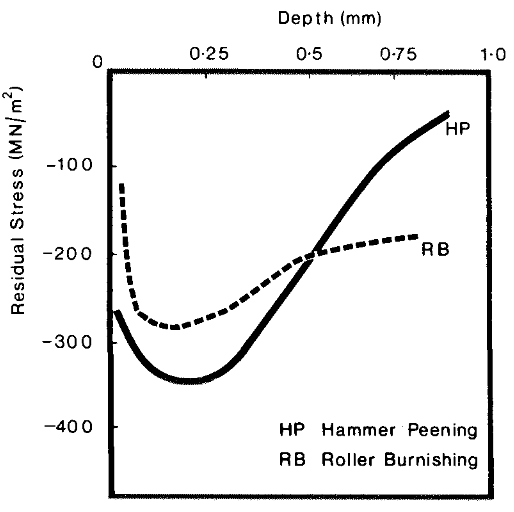

FIG.5 Residual Stress versus Depth curve for Roller Burnishing and Hammer Peening

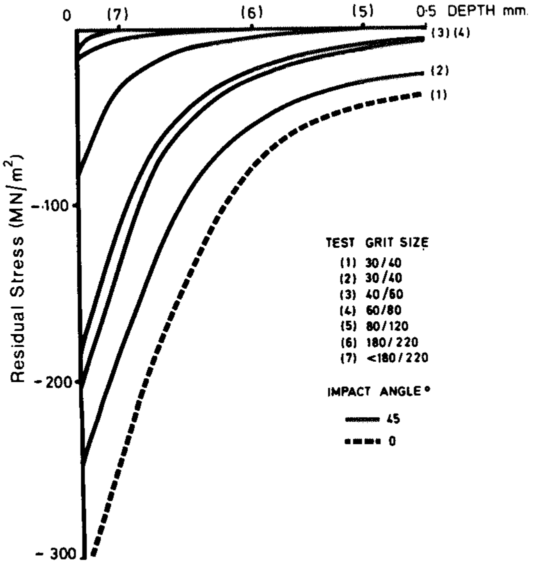

FIG.6 Residual Stress versus Depth curve for Grit Blasting

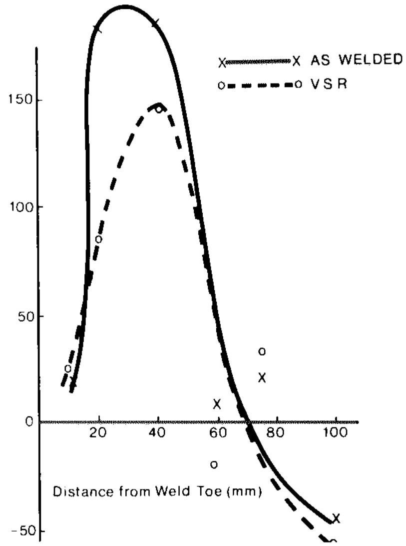

FIG.7 Effect of Vibratory Stress Relieving on surface Residual Stress

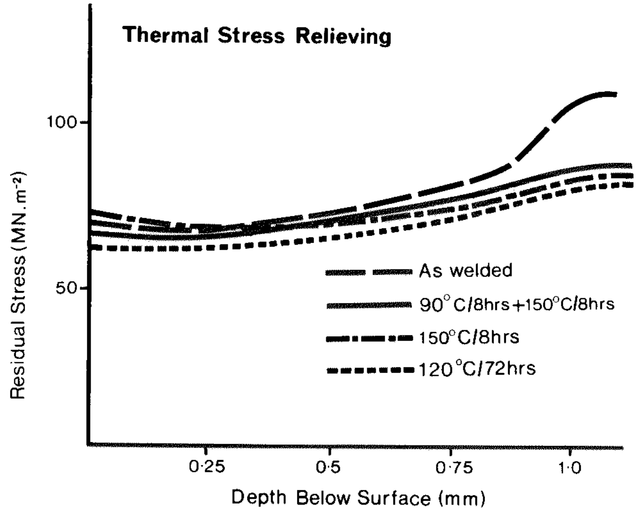

FIG.8 Effect of Thermal Stress Relieving on Residual Stress

Several general features emerge from the results shown in Figs 2 - 6. Firstly, for the majority of treatments the maximum compressive stress appears at a short distance below, rather than immediately at, the deformed surface. This is a common feature of stress distribution induced by peening.
Secondly, each mechanical surface treatment introduced a considerable magnitude of compressive stress.
Thirdly, the depth effect increased with the diameter of the indentor, and decreased with increasing deviation from the normal of the angle of application.

These results illustrate that the stress-depth measurements can distinguish between the various treatments and variations in parameters, and can enable suitable treatments to be selected for prevention of SCC of plate edges. The effect of VSR was one of stress re-distribution (Fig 7). In some cases, the stress was reduced by up to 25% but in other cases it increased. After the treatment, the residual tensile stress remained above the threshold level for SCC, and therefore VSR could not be regarded as a SCC preventive in this structure. It does not however preclude its application to other types of structures or other Al-Zn-Mg alloys, but each case must be evaluated individually.

It is noted from Fig 8 that the stress-vs-depth relationships for the sample not heat-treated and the samples heat-treated were all very similar. The surface stress values were all substantially above that required to initiate SCC. However, it cannot be automatically assumed that SCC will occur in the heat-treated samples because the treatment itself should improve the inherent stress corrosion resistance of the material, and this may be sufficient to prevent cracking. To resolve this doubt, samples were exposed to an environment of 40°C and 95% Relative Humidity. All specimens were found to have cracked within 4 weeks, and therefore it is concluded that there is no advantage to TSR as a SCC preventive of this Al-Zn-Mg alloy using the treatments stated above.

EFFECT OF PEENING PRIOR TO WELDING

The above mentioned results suggest that peening of welded joints can be employed for the prevention of stress corrosion cracking of plate edges. However this must be done before cracking initiates and could involve the periodic removal of the component from the production line, causing inconvenience, delay and increased costs. Peening of plate edges prior to welding would therefore be a considerable advantage provided that the compressive stress induced by peening is still remnant after the subsequent welding process. A simple exercise was carried out, therefore, to determine whether peening was still effective after welding. A cruciform joint similar to that in Fig 1(a) was fabricated from plate which had been peened all over prior to welding. Stress measurements were made by the hole drilling technique at positions equivalent to C1,C2,C3 and C4. The surface stress values are plotted in Fig 9. It is noted that these are as high as those in Fig 1(b), and therefore there is no doubt that the effect of peening is destroyed by subsequent welding, and that this procedure cannot be employed as a stress corrosion preventive. This was confirmed by exposing the cruciform to the hot humid environment mentioned earlier and cracking occurred within three weeks. See Fig 10.

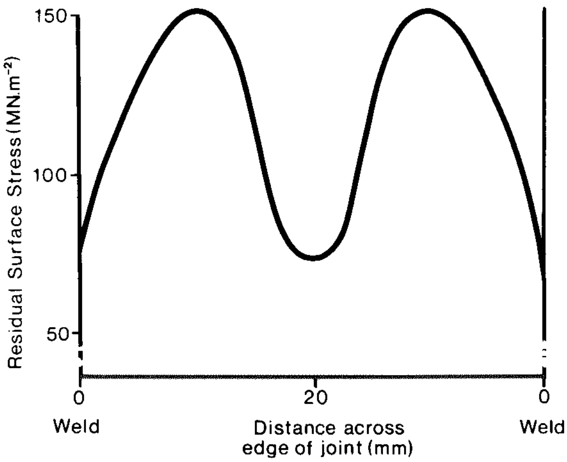

FIG 9. Effect of Welding on Shot Peening

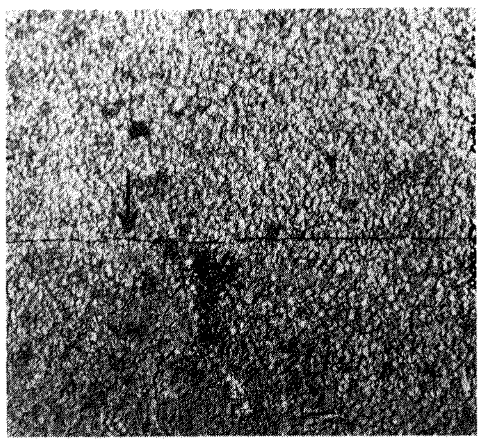

FIG 10. A crack in the Edge of a Cruciform Joint Shot Peened before Welding

CONCLUSIONS

The effect of peening of Al-Zn-Mg alloys on the stress-depth effect introduced is independent of the prior stress distribution.

The various mechanical treatments can be compared in terms of stress versus depth effects on annealed coupons. A suitable technique for determining the stress as a function of depth is the centre hole drilling technique employing an incremental analysis.

It is anticipated that shot, needle, roto and hammer peening, roller burnishing and grit blasting could be employed as preventives for SCC in edges of Al-Zn-Mg alloys in appropriate circumstances if applied in a controlled manner. The actual treatment employed will depend on such factors as the location of the part to be treated, numbers, size, surface finish required etc.

The preventive treatment must be applied to the edges after welding, not before.

The effect of VSR is one of stress re-distribution and it is unlikely that this could be employed as a stress corrosion preventive in Al-Zn-Mg structures without considerably more research.

Little or no benefit was derived from the Thermal Stress Relieving treatments applied.

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