CONTROLLED SHOT PEENING AND ITS EFFECT ON FATIGUE AND STRESS CORROSION CRACKING OF WELDED JOINTS

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Controlled Shot Peening is recognised and widely accepted as a process to increase fatigue strength and stress corrosion cracking and extend life of fabricated components, particularly in high performance applications, by the introduction of compressive residual stress. Fatgue and stress corrosion cracking are also problems commonly encountered, in many areas of industrial activity, where beneficial residual stress induced by controlled shot peening can provide a cost efficient solution.

INTRODUCTION

With increasing use of high strength steels in recent years, the risk of failure due to fatigue and stress corrosion cracking has increased to a great extent. Therefore, it is necessary to guard against the risk of failure due to this type of loading and environment. The influence of welding of the joint behaviour is complex: it is determined by inhomogeneity of the weld metal structure, by the presence of stress concentration and the residual stresses due to a welding process.

It is known that residual welding stresses have a considerable effect on the behavour of structures subjected to fatigue and stress corrosion cracking. Post weld heat treatment (PWHT) is primarily used to reduce the level of residual stresses present in a welded joint. The reduction of residual stresses will lead to a reduction of brittle fracture and improvement in fatigue resistance, stress corrosion cracking and dimensional stability. However, PWHT sometimes gives conflicting results with regard to toughness (1,2) and it is frequently impractical to stress relieve large vessels and structures.

The purpose of this paper is :

- ✱ to specify the Controlled Shot Peening (CSP) technique as a final treatment.
- ✱ to sum up present knowledge of the behaviour of welded structures which has been subjected to CSP, in relation to fatigue and stress corrosion cracking.
- ✱ to finally assess the advantages and difficulties encountered in the applcation of CSP.

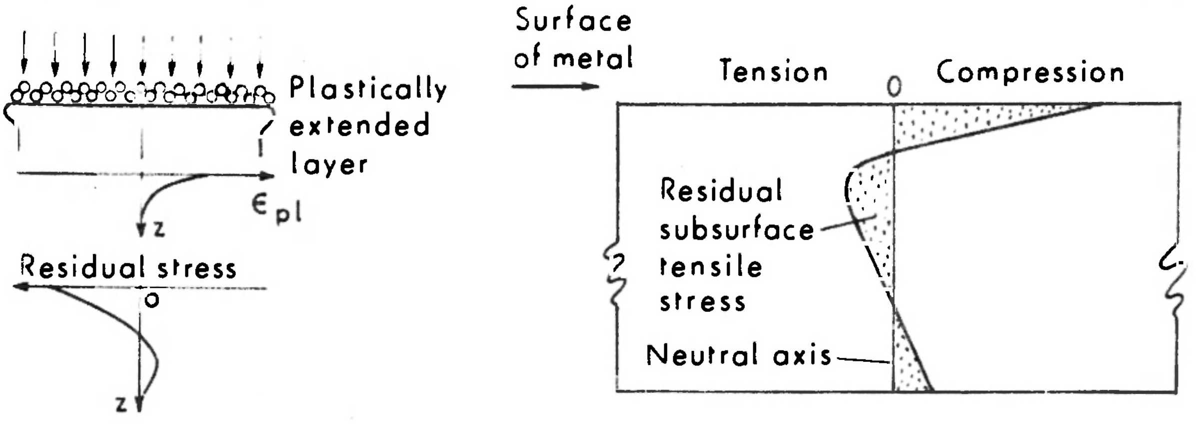
Shot Peening and Specification of Controlled Shot Peening

Shot Peening

Shot peening is the bombardment of the material surface with speherical steel shot, glass or ceramic beads, under controlled conditions, to produce plastic yield at the surface. The multiple impacting produces a uniform high magnitude compressively stressed layer, minimun 50% U T S, at full coverage. Schematic illustration of the formation of residual stresses in shot peening [3] is shown in Fig. 1.

Specification of Controlled Shot Peening

The objective of controlled shot peening is to induce a compressive stress of predictable magnitude and depth. The magnitude is dependent on the yield strength of the metal (Fig.2) and provided uniform cold work is achieved that level will not



(a) Stretching of a surface layer as a consequence of surface hammering

(b) Induced compressive and tensile stresses in shot peened metal with no external load

Fig 1 : Schematic Illustration of the formation of residual stresses in shot peening

vary. Depth is important and the shot-peening parameters are chosen to suit the problem. For instance should the environment not be excessively corrosive or suffer erosion and be reasonably smooth or defect free then a shallow compressive layer is adequate. However, excessive corrosion, erosion or surface defects require maximum depths of cold work otherwise limited benefit will be noted.

The process has a number of variables that affect the depth of residual compressive stress. Control of those variables are important otherwise repeatability and confidence in the technique will suffer. The variables include: shot (size, shape, hardness, alloy), velocity, coverage, angle of incidence, nozzle distance, substrate hardness and substrate roughness. Sometimes if the alloy hardness allows it is better to severely cold work the surface, changing its geometry obliterating the small radius/fillet effect[4].

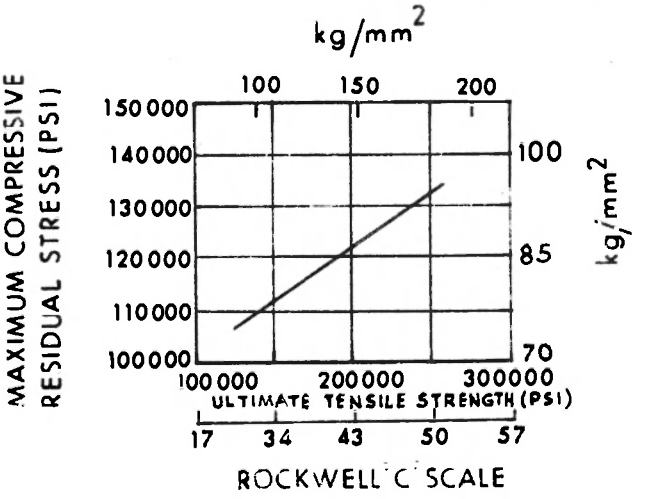


Fig 2 : Residual stress produced by shot peening Vs Tensile strength of Steel

Today shot peening is a well controlled process with all of shot peening parameters specified. The first step starts at the drawing board with the process specifications which include media type, size and hardness, as well as intensity and coverage. Once the specifications are selected, the variables must be measured and controlled to ensure they are being maintained.

A large variety of specifications and standards concerning shot peening is available. Some were issued by specific companies or Industries, others are national standards. Some are internationally accepted. For example, design engineers may want to refer to the united States Military Specificaton MIL-S-131650-Amendment 2, 25 June, 1979.

The main items which should be specified for CSP are as follows:

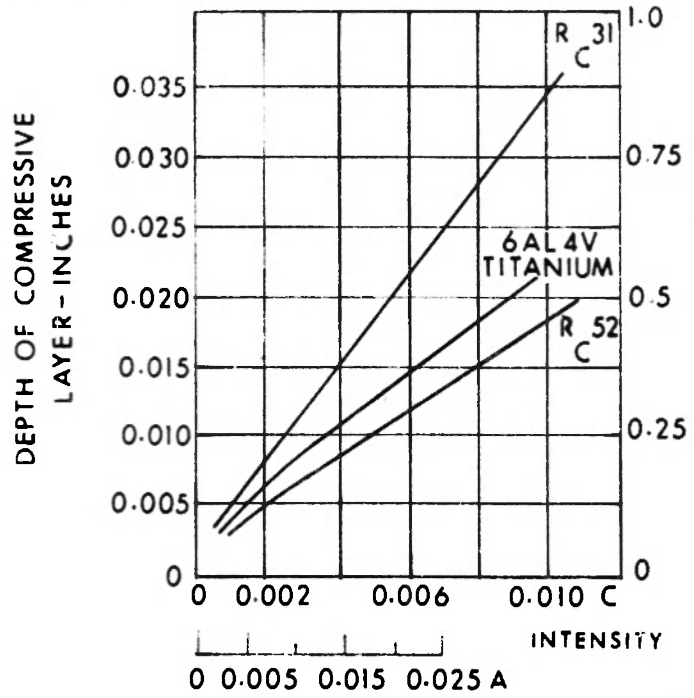


Fig 3 : Depth of compressive stress Vs Almen intensity for steel and Titanium

Almen Intensity

The intensity is an indication of the kinetic energy transfer in the peening process. The Almen intensity works on the principle that if a flat piece of metal is clamped on a solid block and exposed to a blast of shot, it will be curved upon removal from the block. The height of the curved arc serves as a measure of intensity. The Almen system involves standard tests strips of three different thicknesses classed A, C or N (1.29, 2.39, 0.79 mm) and a standard measuring device, called the Almen gage. The Almen intensity specification consists of a number (arc height) and a letter (A, C or N)

Although the Almen intensity alone is not sufficient to defines the results of a peening process, it is the main parameter which should be observed to assure repeatability. The principal advantage of the Almen intensity is that it integrates most relevant factors e.g. Shot velocity, mass and hardness, angle of impingement etc. [5]. Fig. 3 shows the depth of compressive stress vs. ALMEN intensity for steel and titanium.

Coverage

The uniformity of compressive stress is related to the evenness of coverage which is defined as the uniform dimpling or obliteration of the surface. MIL-S-13165B specifies two acceptable method of checking this important factor. (i) Visual examination using a 10 magnification glass, (ii) Peenscan Process which is particularly useful where large areas or fine geometry is involved. The area to be shot peened is first coated with an elastic fluorescent tracer dye (Dyescan) which is sensitive to ultra-violet light and has a rate of removal consistent with coverage on the component surface. At 100% coverage on white fluorescence will be evident and the base metal will appear a deep purple colour under the ultra-violet inspection lamp.

Shot-Peening Media

Media type (cast steel, glass bead or ceramic) chemistry, hardness and size should be specified and controlled. Shot peening media will deteriorate after some period of use causing lower intensity and work piece surface damage. The MIL-131658 specification places of limit on broken or deformed particles allowable in the shot peening machine.

As far as size is concerned larger shot can produce higher intensities but smaller shot produces full coverage more quickly. Use of large shot results in smoother surfaces.

Masking and Processing Sequence

Only in a limited number of cases in peening of the entire part required. Yet masking may be costly and should be specified only when absolutely essential.

Shot peening is a finishing treatment; its value is spoiled by almost any subsequent machining or heat treating processes.

Measurement of Residual Compressive Stresses

A variety of methods are available to measure residual stresses at the surface of the part. Unfortunately, today, there is no practical, non-destructive method for measuring stress distribution. Today, X-ray diffraction measurements may be helpful as additional controls but stress depth and distribution can not be verifed on finished parts.

Shot Peening Equipment

All shot peening must be performed automatically, variables such as nozzle distance, angle of impingement and traverse or rotational speeds can only be reliably maintained by the provision of this type of control. Monitoring of the process by the use of microprocessor machinery is a natural progress where efficiency and close control are to be maintained.

Table 1:
Techological Parameters for the various preliminary shot peening operations.

Shot peening	Shot diameter mean dia.(mm)	ALMEN Intensity	Coverage
1	0.43	(14-16A)	200%
2	0.84	(20-22A)	200%
3	1.40	(8-10C)	200%

The geometry of the weld beads is shown in Fig. 4.

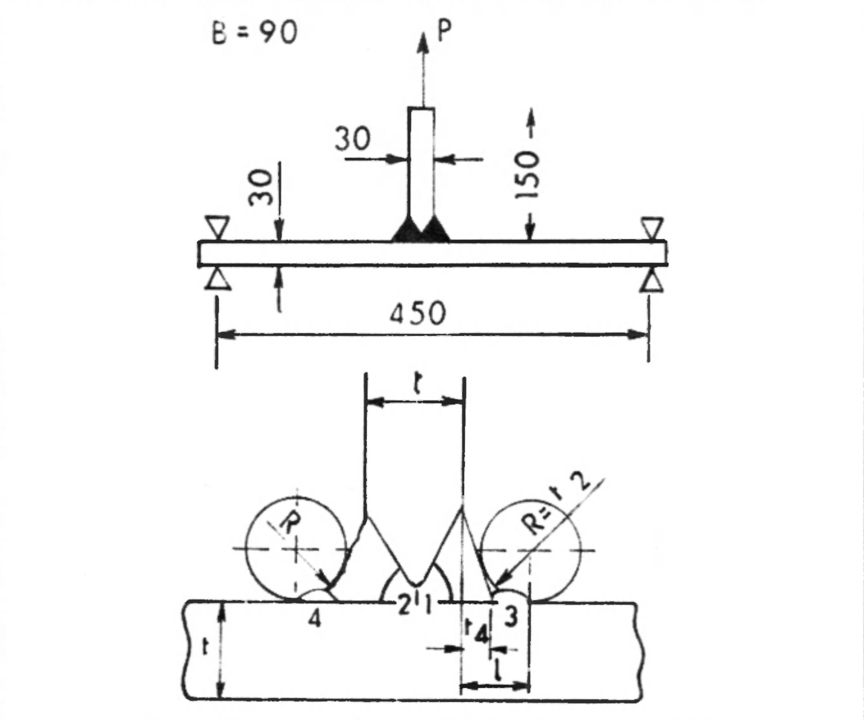


Fig 4 : Geometry of the test specimens and the welds bead

Weld Fatigue and Controlled Shot Peening

In general, the resistance to farigue crack initiation increases with the yield strength or the tensile strength of welded joint. However, the fatigue crack growth rate is relatively uneffected by the yeild strength or the weld micro structure [6]. Because of the insignificant effect of the yield strength of steel on fatigue crack growth, the only way of taking full advantage of steels of high characteristics is to increase the part played by crack initiation in the total life of the welded assembly. For this purpose CSP can be used with the purpose of modifying the range of residual stresses introduced by welding. There is little information on results in relevant literature. However, some of the data reported in the literature [7] is quite encouraging. For example, three shot peening operations with different techonological parameters on T-joints in E 460 steel are given in Table 1.

Fig. 5 shows the condition of residual stresses after shot-peening. The shot-peening operation (1) introduced surface stresses of - 300 MPa, to a depth of approximately 0.15 mm.

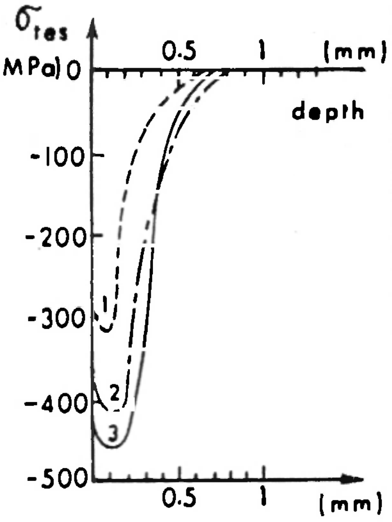


Fig 5 : Distribution of shot-peening stress with depth for different shot peening operations

The shot-peening opeartions (2) and (3) resulted in surface stresses of the order of -400MPa, to a depth of approximately 0.25 mm. Fig. 6 illustrates the remarkable improvement resulting from application of the CSP operation (2) to T joints. Improvement in the fatigue strength at 2 x 10^6 cycles due to shot peening is 84%. The improvement in the fatigue strength obtained by shot-peening is attributed due to residual stress relief and induced compressive stress at the surface. A crack can not initiate in a compressed layer nor propagate into it. Compressive residual stresses add up to service tensile stresses so that surface tensile stresses are considerably reduced. As nearly all fatigue type failures originate at the surface of the part, the shot peening - induced compressive layer is a successful mothod of preventing such failure [7]. However, the shot peening variables have to change in order to obtain required distribution, depth and gradient with different situation to ensure optimum resutls are achieved. It is worth mentioned here that full coverage (100% or more) is essential to a good, reliable, reproductible peening operation.

Stress Corrosion Cracking (SCC) and Controlled Shot Peening

In general, a corrosive medium can have a decisive effect on the life of parts and of steel structures subjected to loading. In welded structure it is generally the Heat Affected Zone that causes concern because of the high residual tensile stresses. SCC is caused by one of four conditions-Residual and or Applied Tensile stress, Corrosive environments, susceptible aloys and time [8]. The critical factors being to ensure that the threshold level of tensile stress is not exceeded by the residual or the applied stress. The applied load coming form pressurization, temperatures dead weight of contents, bolting, wind or wave action. These loads can be low in magnitude but in combination with a residual tensile stress from welding the threshold level can be reached.

Shot peening can prevent SCC by imposing compressive stresses at the surface of the work piece and that the feasibility of shot peening to prevent corrosion of austenitic stainlless steels has been established [8,9.] The beneficial effect of shot peening in relation

Table 2:
Effect of Shot Peening at various percentages of yield on Sulphide stress cracking of 17-4 pH Stainless steel

Applied stress (% Yield)	Non-Peened (hours to failure)	Shot-Peened (hours to failure)
30%	29.8	720NF
40%	37.9	561.0
60%	15.4	538.5
70%	15.2	219.1

NF - No failure, test terminated

Table 3:
Effect of stress Relief on SCC resistance of peened Type 304 stainless steel U-bend specimens

Stress Relief temperature (°C)	Time	Condition	Tensile SCC
538	16	Unpeened	3h
		Peened	103 NF
565	144	Unpeened	10h
		Peened	202 NF

NF - No Failure, test terminated

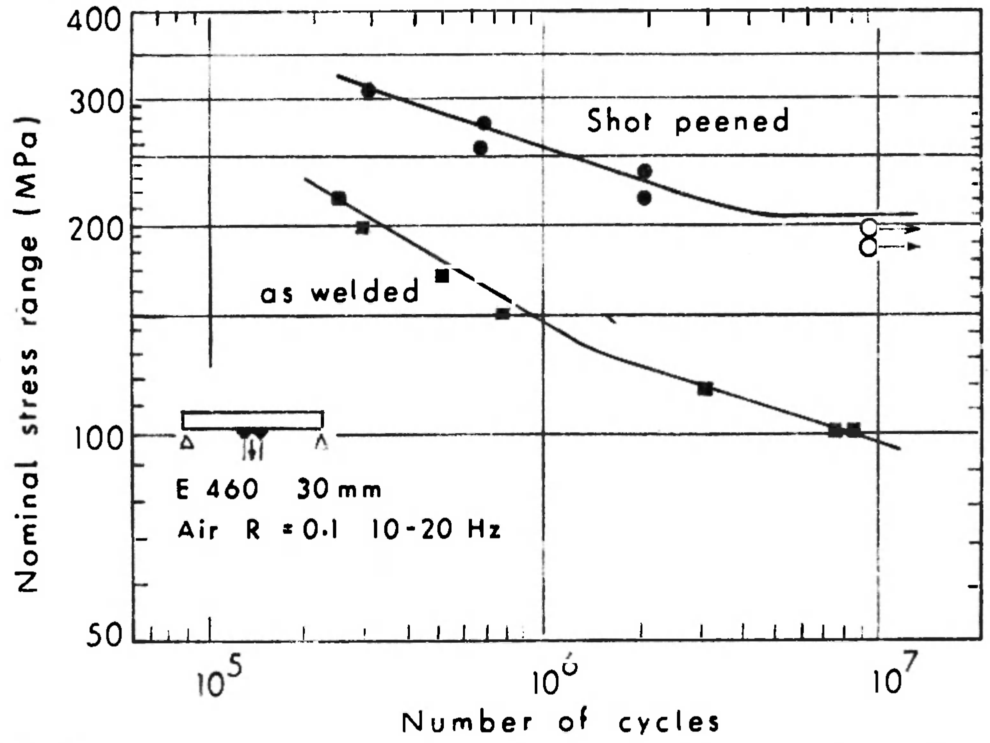


Fig 6 : Fatigue strength of welded joints in steel E460, in the basic post - weld and shot - peened conditions

to SCC has been observed in other materials such as constructional steels, Titanium, Inconels, Hastelloy, Copper silicon and magnsium alloys.

The effects of shot peening in sour gas application on susceptible 17-4 precipitation hardened stainless steel at various percentages of yield is presented in Table 2.

In addition it has been observed that resistance to SCC is retained even at temperatures expected to reduce the level of compressive stress (Table 3)

An overview of various results indicate that CSP technique could enable the use of high strength steels for such aplications with prolong life.

CONCLUSIONS

Controlled shot peening has proved to be a reliable technique for improving the life of welded component. However, sufficient care of its application must be conducted to acheve the right magnitude and depth ot compressive stress. CSP is an acceptable procedure under A.S.M.E. Boiler and Pressure Vessel Code. Therefore, in situation where fatigue, SCC cause problems it is an economic process to use on structures, vessels etc.

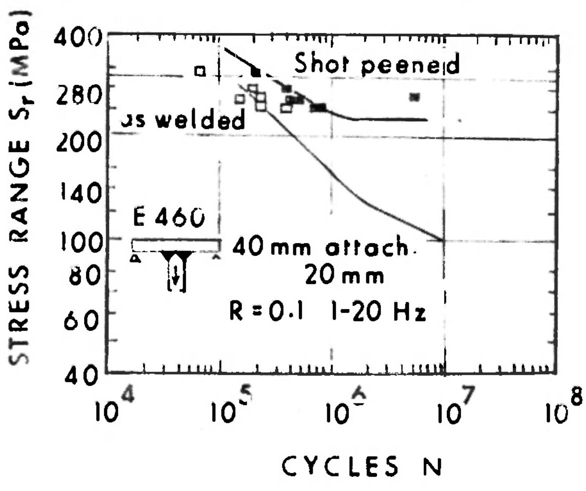


Fig 7 : Environment effect on the fatigue strength of welded joints after shot peening

In applications where the critical stress levels are known and thermal stress relief is adequate even though 15-20% of the HAZ stress can still be present after treatment, then CSP can often be preferential on economic grounds only. In other words the technique can be used as a stress relieving operation where the residual compressive stress induced is a bonus but not essential. Local CSP has shown to be considerably cheaper on many structures than thermal stress relief.

An additional benefit of the treatment is that it is sometimes difficult on structures which exhibit cracking to determine whether the problem is surface related or the material or weld has a major sub-surface defect. On a structure where cracking is experienced and some sub-surface defects are suspected but environment problems are believed to exist also it would be feasible to grind out all cracks and re-weld but this would be time consuming and expensive. An alternative would be to shot-peening during a maintenance period and re-examine at a subsequent down time. Those cracks which are environment related would be eliminated and those caused by sub-surface welds flows of a major nature may re-appear. Effort can then be expended only on these i.e. grinding out welding, considerably reducing the re-work.

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