EFFECT OF SHOT PEENING ON RESIDUAL STRESS AND STRESS CORROSION CRACKING FOR COLD WORKED AUSTENITIC STAINLESS STEEL

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ABSTRACT

The effectiveness of shot peening as a residual stress improving technique for irradiation hardening materials was investigated using 20% cold worked stainless steel plates which simulated the hardness of irradiation hardening materials. Isotropic compressive residual stress could be built into such high strength materials by shot peening. The hardness of compressive stress layer further increased due to cold working by shot peening. It has been confirmed by $MgCl_2$ immersion tests that the stress corrosion cracking (SCC) at the welding heat affected zone is effectively suppressed by shot peening.

KEY WORDS

Stress corrosion cracking, hardness, residual stress, $MgCl_2$ immersion test, light water reactor, compressive stress, welding heat affected zone, irradiation hardening

INTRODUCTION

In-core components in light water reactors, which are made of austenitic stainless steel, are irradiated by fast neutron to increase their mechanical strength remarkably (irradiation hardening). The applicability of shot peening to these high strength materials was examied in this study, to enhance the structural integrity and the life of the in-core components.

It is known that the tensile residual stress which occurs by a welding heat cycle is a cause of stress corrosion cracking (SCC). It has been reported that corrosion resistance in some stainless steels was improved by shot peening(1)(2). It has also been experimentally shown that the application of shot peening to a repair welded portion in a reactor tank in a practical chemical plant effectively prevented the occurrence of SCC(3). On the other hand, the results of constant strain rate tests in high purity water at 288°C have shown that shot peening promote crack initiation to accelerate the SCC susceptibility of the material(4)(5).

It is necessary to clarify the effect of the exposed environment and applied external stress conditions for shot peened components on its feasibility for practical applications to in-core components. In this study, the effect of shot peening conditions to the formation of the compressive stress filed, and its effectiveness to SCC according to 42% $MgCl_2$ immersion tests were examined using 20% cold worked Type 304 stainless steel, which has almost the same hardness as 1×10^{21} n/cm^2 fast neutron irradiated stainless steel in light water reactors.

EXPERIMENTAL

1. Specimen preparation

The Vickers hardness of 20% cold worked Type 304 stainless steel plates was about 300 which corresponded to that of materials irradiated with 1×10^{21}n/cm^2 fast neutrons in light water reactors. An anisotropic stress field was built by one directional cold working, the tensile residual stress remained along the rolling direction and the compressive stress remained along the transversal direction to the rolling direction.

2. Shot peening conditions

Shot peening was carried out using an air blast type machine with steel shots (Hv: form 430 to 540). The shot peening conditions are summarized in Table 1. The diameter of the shots were 0.3, 0.6, and 1.2mm, and the duration of shot peening was 0.4, 0.8 and 1.2 sec/cm^2, and the other peening parameters such as the pressure of compressed air, nozzle diameter, distance between the nozzle and specimen, and injection angle were constant.

Table 1 Shot peening conditions

Shot	Steel (Hv: 430~540)
Shot diameter	0.3, 0.6, 1.2 (mm)
Duration of shot peening	0.4, 0.8, 1.2 (sec/cm^2)
Pressure of compressed air (air blast machine)	5 (kg/cm^2)
Nozzle diameter	9 (mm)
Distance between nozzle and specimen	about 150 (mm)
Injection angle	90 degree

3. Residual stress measurement

The residual stresses along two axes were measured, which were along the parallel (σ_x) and transversal (σ_y) directions to the rolling direction, using the X-ray diffraction method. The residual stress depth profiles were obtained by removing the surface layer electrolytically.

4. Stress corrosion cracking (SCC) tests

The SCC susceptibility change due to shot peening was evaluated by $MgCl_2$ immersion tests. Welded specimens were used for the SCC tests, which were prepared by depositing welding bead on the 20% cold worked plates (30×60×8t). Filler (F) and no filler (NF) welding specimens were prepared by TIG (Tungsten Inert Gas) welding with 16 kJ/cm power.

After the surface residual stress was measured along the transversal direction of the welding bead for the F and NF welding specimens, some specimens were shot peened, and the others were not. One half area of every shot peened specimen was processed by masking the other half, and the surface residual stress was measured for the shot peened area.

These specimens were immersed in a boiling 42% $MgCl_2$ solution for 50 hours, and the tests were interrupted at immersion times of 20, 25.5, and 31 hours to observe the appearance of the specimens.

RESULTS AND DISCUSSION

1. Effect of shot peening conditions on residual stress

Figure 1 shows the surface residual stress change by shot peening using 1.2mmϕ shots. An isotropic high compressive stress field was built by shot peening to the work hardening material, and the compressive stress decreased slightly with increasing duration of shot peening. Similar results were obtained in cases of using 0.3 and 0.6mmϕ shots. Surface stress was thought to slightly relax due to long time shot peening, and its value actually decreased.

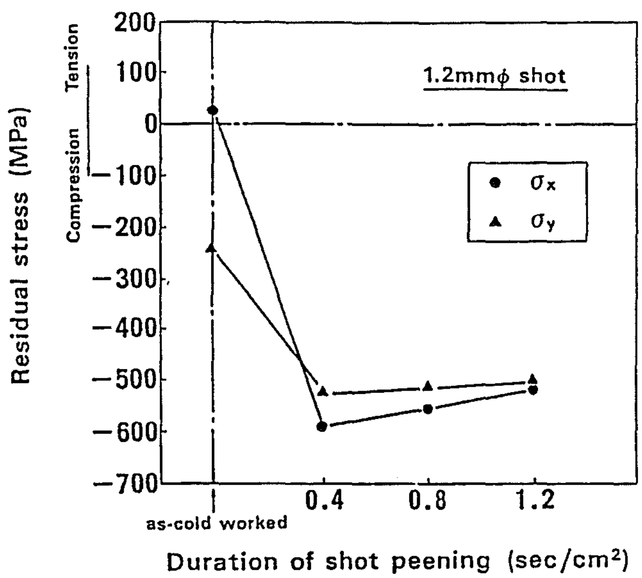

Fig.1 Surface residual stress change by shot peening

The residual stress depth profiles from shot peened specimens using 0.3mm shot for 0.4sec/cm^2 and 1.2sec/cm^2 are shown in Fig.2 and 3. The thicknesses of the compressive stress layer were almost the same between the two cases, and compressive stress was converted into tensile stress at depths from 120 to 180μm. Figure 4 shows the residual stress depth profile when using 1.2mmϕ shots. The thickness of the compressive stress layer obtained using 1.2mmϕ shots was beyond 500μm, and the maximum compressive stress was built at the depth of about 100μm. The thickness of the compressive stress layer remarkably depended on the shot diameter, and the stress field just beneath the surface was thought to relax due to the shot peening using large diameter shots (1.2mmϕ).

2. Surface roughness

The surface roughness profiles of the specimens which were shot peened using 0.3, 0.6 and 1.2mmϕ shots are shown in Fig.5. They directly reflected for the shot diameter, and the maximum and average roughnesses for the 1.2mmϕ shot peened specimen were above twice larger than for the 0.3mmϕ shot peened specimen.

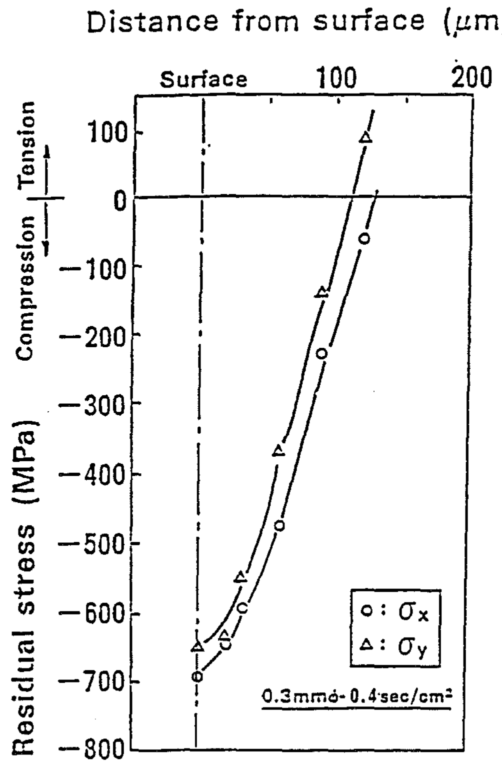

Fig.2 Residual stress depth profile from 0.3mmϕ – 0.4sec/cm^2

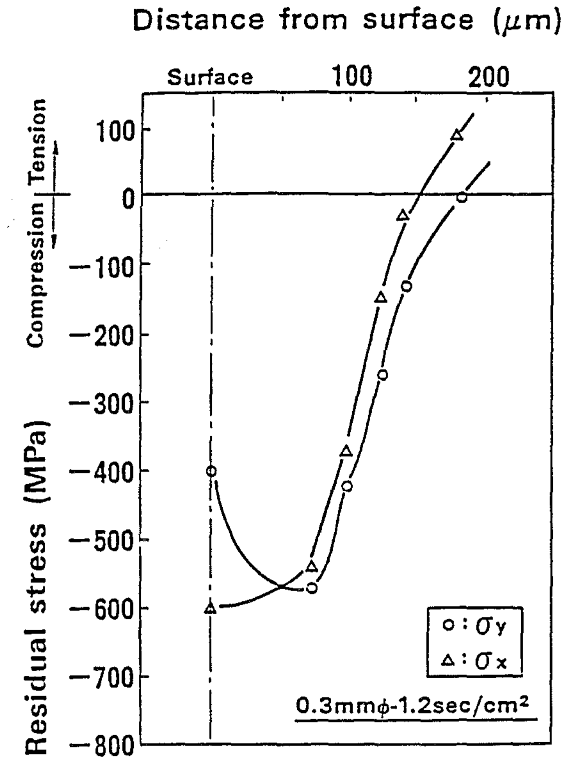

Fig.3 Residual stress depth profile from 0.3mmϕ – 1.2sec/cm^2

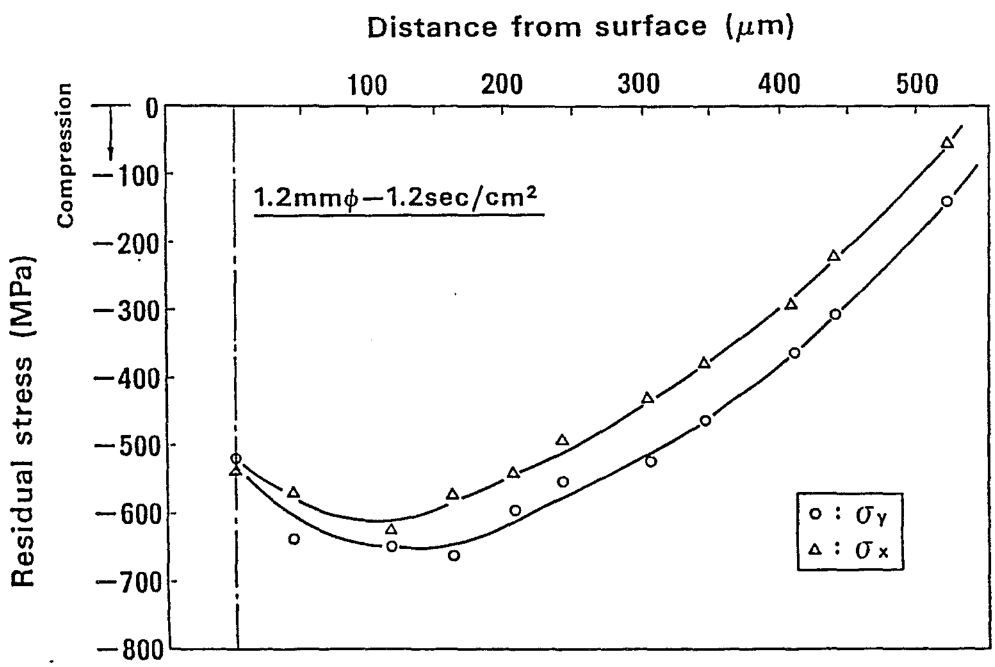

Fig.4 Residual stress depth profile from 1.2mmϕ – 1.2sec/cm^2

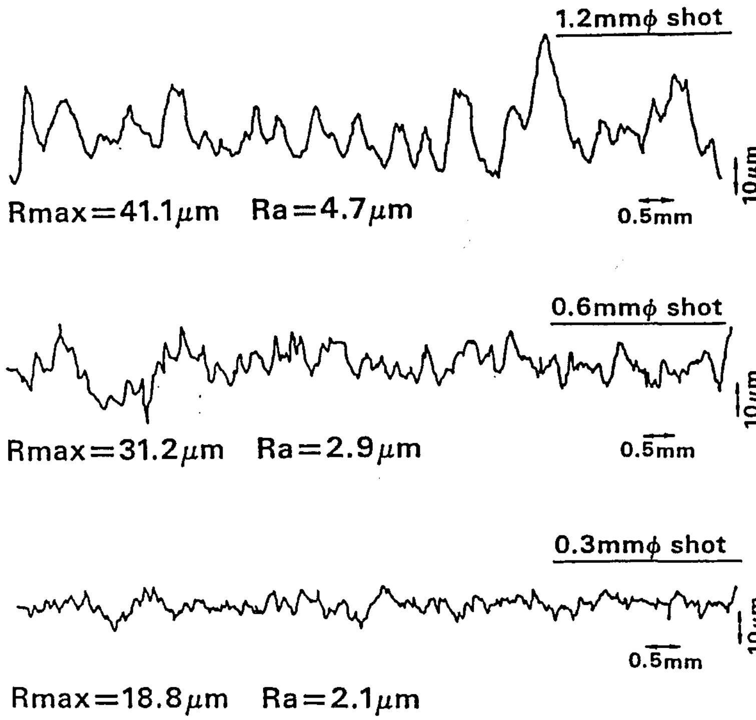

Fig.5 Surface roughness of shot peened specimen

3. Hardness of the compressive stress layer

Vickers hardness at the cross section of the shot peened specimens were measured at intervals of 50μm from the surface. Vickers hardness at every depth was determined by averaging five point measured values.

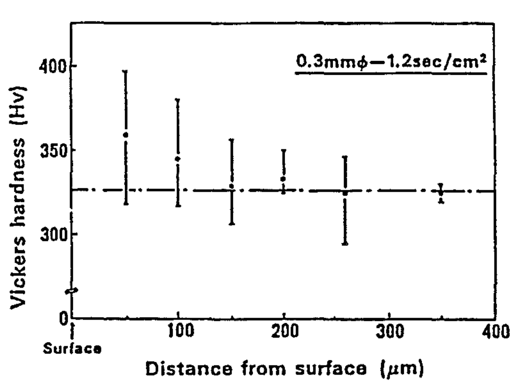

Fig.6 Hardness depth profile from 0.3mmφ -1.2sec/cm² shot peened specimen

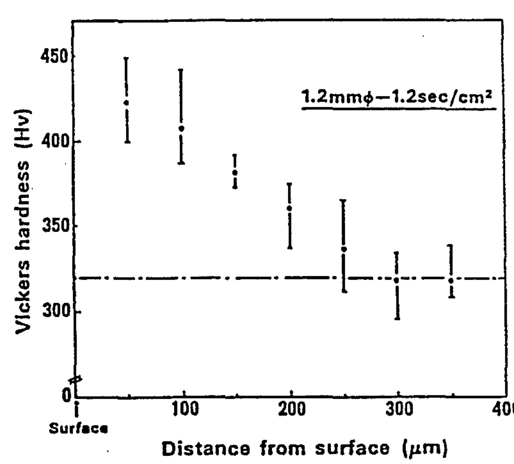

Fig.7 Hardness depth profile from 1.2mmφ -1.2sec/cm² shot peened specimen

Figure 6 and 7 show the Vickers hardness depth profiles from the 0.3mmϕ and 1.2 mmϕ -1.2 sec/cm^2 shot peened specimens. The shot peened surface layer was further work hardened, and increased its strength. The strength of the 1.2mmϕ shot peened region was higher than that of the 0.3mm shot peened region. Although the work hardened layer by 1.2mm shot peening was thicker than that by 0.3mm shot peening, the thickness of the layer did not correspond to that of the compressive stress layer.

4. Stress corrosion cracking (SCC) tests

The surface residual stress distributions from as–welded (F and NF welding) and shot peened (0.3mm, 1.2mmϕ shots) specimens are shown in Figs. 8 and 9. Tensile stress was built at both sides of the weld metal for the F (filler) and NF (no filler) as–welded specimens, and

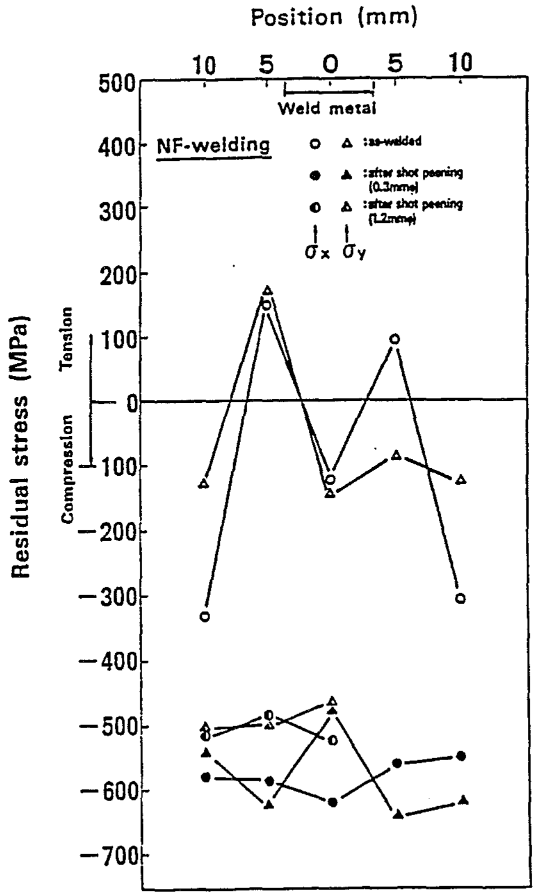

Fig.8 Surface residual stress distribution from as–NF (no filler) welded and shot peened (0.3mmϕ, 1.2mmϕ) specimens

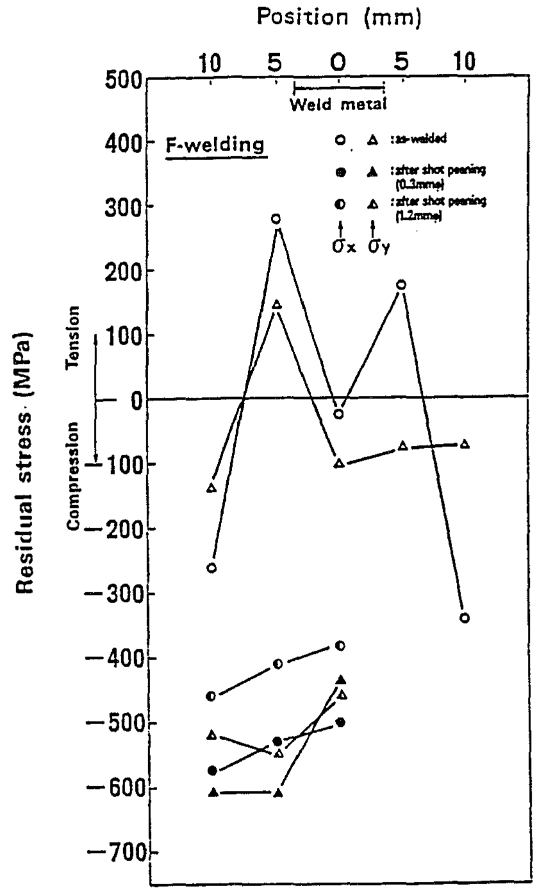

Fig.9 Surface residual stress distribution from as–F (filler) welded and shot peened (0.3mmϕ, 1.2mmϕ) specimens

the value for the as–welded specimen with the filler was higher compared with the case without the filler. The stress components parallel to the welding bead (σ_x) tend to be larger than σ_y at the points for both specimens. An isotropic compressive stress field was built by shot peening independent of the shot diameter, and the stress distribution after shot peening was almost uniform independent of the as-welded stress distribution. Therefore, shot peening is thought to be effective as a stress improving technique for tensile stress introduced by welding.

These as-welded and shot peened specimens were immersed in boiling 42% $MgCl_2$ to evaluate the effectiveness of shot peening to stress corrosion cracking. Stress corrosion cracking occurred at the welding heat affected zone in the F (filler) and NF (no filler) welded specimens, corresponding to the high tensile stress field at an immersion time for 20 hours, but the cracks did not further extend for a longer immersion time. On the other hand, there were no cracks in the shot peened area independent of the shot diameter. The results are summarized in Table 2. It has been confirmed that shot peening effectively retards the stress corrosion cracking using $MgCl_2$ immersion tests.

Table 2 Results of $MgCl_2$ immersion tests

NF—welding	Crack
NF+0.3SP	No crack
NF+1.2SP	No crack
F—welding	Crack
F+0.3SP	No crack
F+1.2SP	No crack

NF:no filler F:filler SP:shot peening

CONCLUSION

The following conclusions have been obtained in this study.

1. An isotropic compressive residual stress is built in 20% cold worked Type 304 stainless steel, which simulated neutron irradiation hardening materials, by shot peening.
2. The hardness of the compressive stress layer remarkably increase due to work hardening by shot peening, and the magnitude and thickness of the work hardening layer depend on the shot diameter as well as the compressive stress profile.
3. It has been confirmed by $MgCl_2$ corrosion tests that the susceptibility to stress corrosion craking (SCC) is considerably reduced by shot peening.

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