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Reduction of Residual Stresses in Weldments with Explosive Treatments

Explosive detonation is effective in reducing residual stresses in weldments, and it offers an alternative to conventional residual stress reduction techniques

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ABSTRACT. A technique is described that uses explosives to shock load welded structures to reduce residual stresses. Explosives were applied to butt joint weld specimens of ASTM A36 structural steel. The shock loads substantially reduced longitudinal tensile residual stresses in the weld heat-affected zone and, in some cases, induced compressive residual stresses. Since fatigue failures are often exacerbated by residual stresses, these results indicate that explosive treatments have potential as an effective method for extending the life of welded structures.

Introduction

Residual stresses have often been identified as contributing factors in the failure of welded steel bridges (Refs. 1, 2). Several techniques exist to reduce the susceptibility of welded structures to failure from residual stresses; however, these techniques can be difficult to apply due to limited access to the affected areas or extremely hazardous work environments.

Shock loading welded structures with explosives to reduce residual stresses is virtually unknown in the U.S., but is commonly used in Russia (Refs. 3–8). Preliminary investigations have been performed in the U.K. (Ref. 9) and the People's Republic of China (Ref. 10), and the technique is the basis for a Japanese patent (Ref. 11) and an American patent (Ref. 12). The technique produces a controlled shock wave through the welded joint by detonation of a strip or cord of explosive in contact with the weld-affected area. Variables in the explosive treatments that allow control of residual stress results include type of explosive, amount of explosive, explosive configuration, and use of buffers between the explosive and the welded structure. In the present study, we examine the effect of explosive treatment variables on the reduction of residual stresses in test specimens with welds that are typical of those found on steel bridges.

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KEY WORDS

Explosive Treatments
Residual Stresses
Residual Stress Reduction
Shock Load Structure
Butt Joint Welded Plates
Structural Steel
Tensile Strength
Compressive Strength
Cord Explosives
Sheet Explosives

Experimental Procedure

Each specimen was fabricated from two sections of rectangular bar stock 12.5-mm thick, 76-mm wide, and 305-mm long (0.5 X 3 X 12-in.) that were butt joint welded together along their length. The plate material was ASTM A36 structural steel, which is a plain carbon steel designed for general structural purposes in riveted, bolted, or welded construction of bridges and buildings. The nominal composition is 0.26% max C, 0.04% max P, 0.05% ma. S, and the balance Fe. The specified tensile requirements are 250 MPa (36 ksi) yield strength, 400 to 550 MPa (58–80 ksi) ultimate tensile strength, and 23% elongation in a 50-mm (2-in.) gauge length.

A single V-groove edge preparation (60-deg minimum) was used with a 3-mm (0.12-in.) maximum root face and a 2-mm (0.08-in.) maximum root opening. Manual shielded metal arc welds were applied using 3-mm E7018 electrodes at 130 A in the flat position. After five passes were made in the V-groove, the plate was turned over, a groove was cut on the backside with an air carbon arc electrode, and two final passes were made.

Shock treatments were performed with sheet or cord explosives. For the shock treatments with sheet explosive, a 6.4-cm-wide (2.5-in.) strip of explosive and buffer materials were placed over the weld bead along the length of each specimen. The combinations of explosive and buffer materials that were used are described in Table 1 and shown in Fig. 1. The sheet explosive (Detasheet C[1]) was either 0.08 or 0.11 cm (0.03 or 0.04 in.) thick. Detasheet C has a nominal density of 1.48 g/cc and a composition of 63% PETN (pentaerythritol tetranitrate) and 8% NC (nitrocellulose), with the balance an elastomeric binder. For

Table 1 — Shock Treatment Designation Description

Shock Treatment Designation	Explosive Type	Thickness or Diameter cm (in.)	Buffer[a]	Detonation Direction[b]
AW	None	—	—	—
C	Cord	0.3 (0.12)	None	Longitudinal
S30	Sheet	0.076 (0.03)	None	Longitudinal
S30A	Sheet	0.076 (0.03)	Type A	Longitudinal
S30B	Sheet	0.076 (0.03)	Type B	Longitudinal
S30C	Sheet	0.076 (0.03)	Type C	Longitudinal
S30T	Sheet	0.076 (0.03)	None	Transverse
S42	Sheet	0.11 (0.042)	None	Longitudinal
S42B	Sheet	0.11 (0.042)	Type B	Longitudinal
S42D	Sheet	0.11 (0.042)	Type D	Longitudinal

(a) Buffer designations refer to layers of materials between the specimen and the explosive as shown in Fig. 1.
(b) Detonation direction refers to the direction of the explosive front relative to the weld direction. In a longitudinal detonation, the explosive front moves over the surface of the weldment parallel to the weld length. In a transverse detonation, the explosive front moves over the surface of the weldment perpendicular to the weld length.

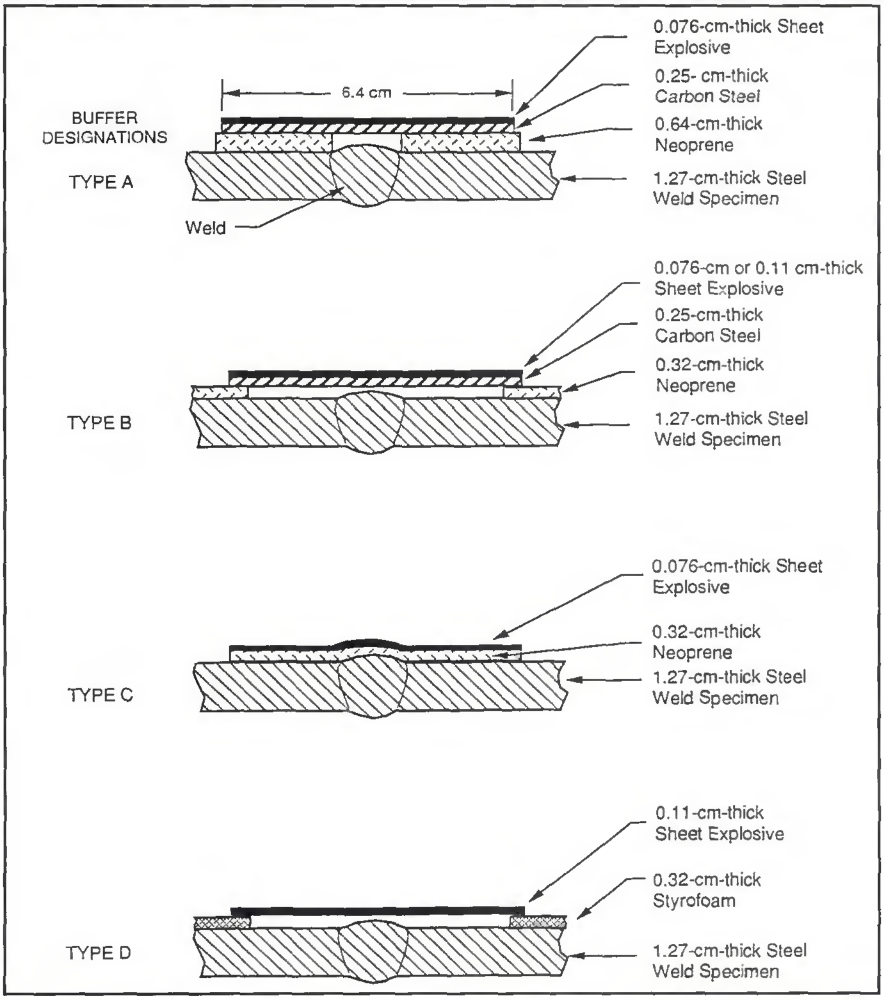

Fig. 1 — Buffer designations for shock treatments using sheet explosive.

the shock treatments with cord explosive, one cord was positioned on either side of the weld in contact with the weld metal and the heat-affected zone. The cord explosive (Primacord[2]) was 3 mm in diameter and contained 0.21 g/cc of PETN. The two cords of explosive were detonated from a single source.

Residual stresses were measured by the hole-drilling strain-gauge method in accord with ASTM Standard E837-81 (Ref. 13). Readings were made in the heat-affected zone and base metal on the shock-loaded surface of the weldment and, in some cases, on the surface opposite from the shock load. Because the hole-drilling technique is not accurate at residual stress levels near or greater than the yield stress (Ref. 14), readings greater than the nominal yield stress for A36 steel are reported as equal to the nominal yield stress (250 MPa).

Results

Figure 2 shows longitudinal residual stress measurements on as-welded and shock-treated specimens. In general, all shock treatments reduced the tensile residual stresses near the weld and reduced the compressive residual stresses in regions remote from the weld. Shock treatment with cord explosive reduced the longitudinal residual stresses to about 65% of the yield stress at locations near the weld (*i.e.*, about 2 cm from the weld centerline), whereas, the sheet explosives produced larger reductions in the longitudinal residual stress near the weld (*i.e.*, to about 40% or less of the yield stress). No clear trend in the residual stress level is evident as a function of variations in the buffers; however, the Type A buffer appears slightly less effective, and the Type B buffer appears slightly more effective in reducing residual stresses. Measurements of the residual stresses on the side of the specimens opposite the shock-loaded surface (Fig. 3) indicate that the treatments produced compressive residual stresses whether the explosive front moved parallel or transverse to the weld line. The buffered shock treatments left small tensile residual stresses near the weld. The transverse residual stresses present before and after shock loading butt joint welded specimens are shown in Figs. 4 and 5. The as-welded condition exhibited low-compressive residual stresses; however, after shock treatment, these stress levels increased to slightly above zero. The 0.08-cm-thick explosive treatment in which the explosive front moved

1. *Detasheet is a registered trademark of E. I. DuPont de Nemours & Co., Inc.*
2. *Primacord is a registered trademark of Ensign-Bickford Co.*

transverse to the weld line produced a substantial increase in the transverse residual stresses near the weld to a tensile value of about 175 MPa (25.4 ksi). Residual stress measurements made on the side opposite the shock loaded surface revealed that shock-loading slightly increased the magnitude of the compressive transverse residual stresses in most cases.

Discussion

Shock treatments generally decreased the longitudinal tensile residual stresses on the shock-loaded surface but often changed the transverse residual stresses from slightly compressive to slightly tensile. Nevertheless, the relative magnitudes of these changes indicate that shock treatments have a positive overall effect on residual stress distributions. These effects are likely to result in improvements in properties that are adversely affected by large tensile residual stresses, *e.g.*, fatigue and stress corrosion cracking.

The transverse residual stresses on the shock-loaded surface increased as a result of shock loading although the longitudinal residual stresses decreased. The development of transverse residual stresses appears to be enhanced when the explosive is detonated so that the shock front moves perpendicular to the weld line. The reason that the tensile stresses arise may be that the shock load plastically distorts the plate in the transverse direction so that bending from the shock loading plastically stretches the plate surface farthest from the explosive more than the surface nearest the explosive. After the shock load is released, the plate recovers elastically, which results in high compressive residual stresses at the surface of the plate opposite the explosive (*i.e.*, where the plastic stretching was greatest) and tensile residual stresses on the surface where the explosive had been applied.

The residual stress patterns in the butt joint welded plates were altered less by the shock loads from the cord explosive than by the sheet explosive treatments. This is probably due to the poorer coupling between the plate and the explosive that results from the cord explosive geometry. Details of the buffering layers did not result in substantial consistent differences in the resulting residual stress pattern.

Conclusion

It is clear from present data that substantial reductions in the longitudinal residual stresses in weldments are produced by shock loading. It is reasonable

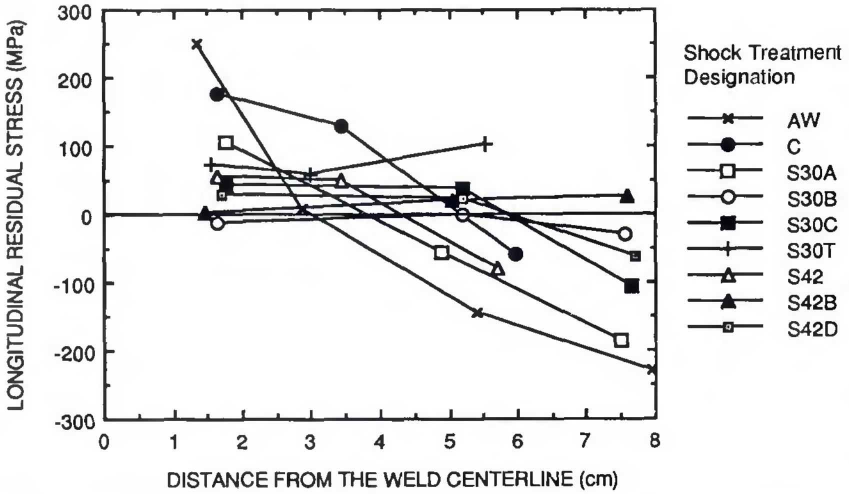

Fig. 2 — Longitudinal residual stresses at the shock-loaded surface of butt joint weld specimens.

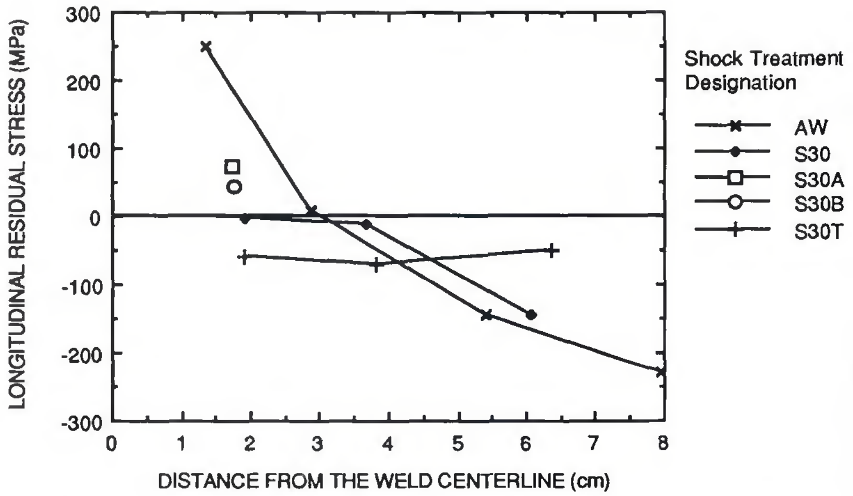

Fig. 3 — Longitudinal residual stresses opposite the shock-loaded surface of butt joint weld specimens.

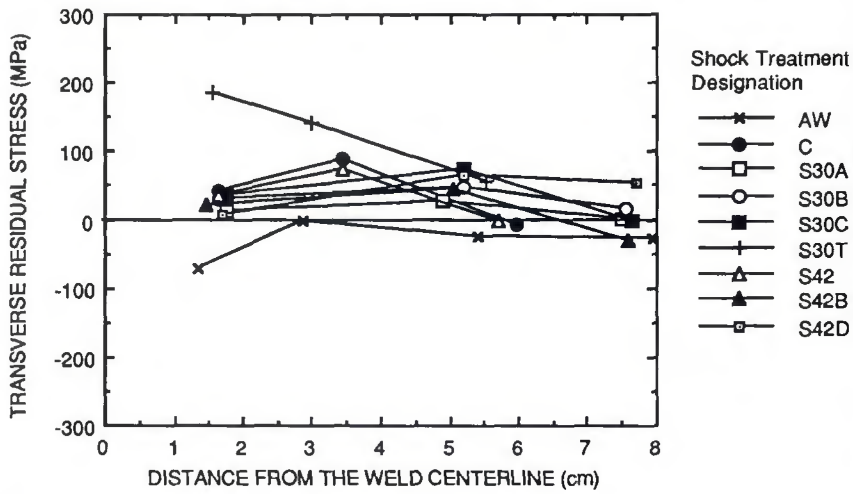

Fig. 4 — Transverse residual stresses at the shock-loaded surface of butt joint weld specimens.

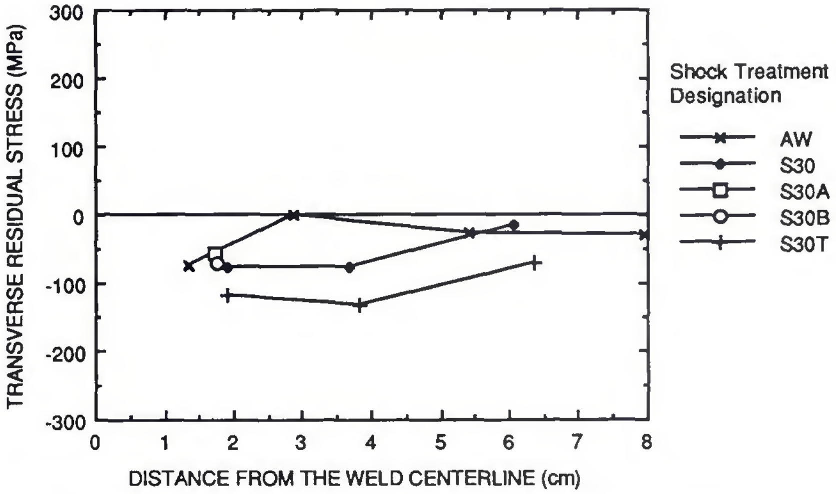

Fig. 5 — Transverse residual stresses opposite the shock-loaded surface of butt joint weld specimens.

to expect, therefore, that shock treatments could offer an alternative to traditional surface treatments (such as peening) that are used to reduce tensile residual stresses at the surface of a weld. To determine the causes and practical effect of shock treatments to welds, this investigation will be extended to examine the microstructure and mechanical properties (especially fatigue) of shock-loaded welds.

Acknowledgments

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