AMERICAN CONSULTING ENGINEERS COUNCIL'S

AFFILIATE

HEAVY MOVABLE STRUCTURES, INC.

4TH BIENNIAL SYMPOSIUM

NOVEMBER 10TH - 12TH, 1992

SHERATON DESIGN CENTER
FT. LAUDERDALE, FLORIDA

SESSION
WORKSHOP NOTES

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"What Amount (Stress Reduction) Benefits Fatigue Life?"

WHAT AMOUNT OF STRESS REDUCTION BENEFITS FATIGUE LIFE?

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INTRODUCTION

We attend technical society conferences to learn something new to solve the problems facing our realm of involvement. Fatigue cracking of large structures is one of these problems. Occasionally, a catastrophic, fatal failure propels the subject to the top of the conference agenda, only to be suppressed on subsequent meetings by more urgent issues. Fatigue crack propagation is an ever present phenomenon and deserves the attention on a consistent basis.

Whether we are involved with new construction or retrofit, when designing for fatigue, residual stress reduction should be considered as suggested in the American Welding Society Handbook, page 130.(1)

"Localized stresses within a structure may result entirely from external loading, or may be a combination of applied and residual stresses. Residual stresses are not cyclic, but they may augment or detract from applied stresses, depending upon their respective sign (tensile stresses are +, compressive -). For this reason it may be advantageous to induce, if possible, compressive residual stress in critical areas of a weldment where cyclic applied tensile stresses are expected. This may be accomplished by a welding sequence that controls the residual stresses from welding, or by a localized treatment that acts to place the surface in compression."

Let us review the various forms of stress reduction and localized treatments that place fatigue critical details in compression. This may be a timely opportunity, as existing structures age and develop fatigue cracks in the following structural details:

1. Cover plate termination weld toe
2. Tack welds
3. Corrosion notches
4. Flame cut coping
5. Holes drilled to arrest cracks

We can wait until the cracks appear requiring more expensive solutions or propose retrofitting existing fatigue critical details.

POST WELD HEAT TREATMENT

By definition "stress relief" means heating of a metal part to a designated temperature and slow cooling with the purpose of reducing residual stresses introduced in the heat affected zone during welding.

Unfortunately a properly planned and controlled furnace stress relief can be a costly and time consuming operation, particularly in structures containing cross sections that vary significantly in thickness and mass. To avoid distortion and the introduction of a new set of undesirable residual stresses, it is often necessary to ramp the heating and cooling stages (step-up and step-down) to equalize any temperature differences between them and heavy sections at each heating and cooling step.

Local stress reliefs, often required because of the large size and/or location of the structure always produce a thermal gradient between the heated and unheated adjacent areas of the structure, with the resultant introduction of some undesirable residual stresses, albeit hopefully in non-critically loaded areas.

Even under the best of circumstances, however, most furnace stress relief operations only reduce between 60-70% of undesirable residual stresses because of time and cost restraints. The percent reduction accomplished by local stress relief is often significantly less for similar reasons.

Finally, there are a number of high strength constructional steels, stainless steels and nickel alloys, both welded and unwelded, which cannot be stress relieved at the normal temperatures used for such operations, due to metallurgical changes which can seriously degrade toughness and notch sensitivity, or reduce the resistance of the alloy to intergranular and/or stress corrosion resistance.

The above is not to imply that all post welding thermal treatments, for example, are detrimental and should be discontinued. On the contrary, in some steels, where welding produces a re-hardened weld and/or weld heat-affected-zone (HAZ), it is usually essential to perform a post welding thermal treatment. The purpose of this treatment, however, is more properly termed "tempering" to reduce the hardness and to increase the toughness of the weld and/or HAZ, rather than a thermal stress relief.

The restriction of not being able to thermally stress relieve does not leave us without any alternative. Reduction of detrimental residual tensile stresses can be accomplished by other means. Let us compare the stress reduction at the surface as measured by X-ray diffraction for a number of different methods. At best for thermal "stress relief" on a 50,000 PSI ultimate tensile strength steel, the residual tensile stresses from welding as high as the yield strength (35,000 PSI) can be reduced to 5,000 to 10,000 PSI tensile stresses.

OVERLOADING

The first application of a live load on such a structure as a simple girder bridge, the stresses introduced on the tension side of the I-beams should reduce the residual tensile stresses and convert them to compressive. This would be true if the lower flange surface contained transverse welds, such as the termination welds of a cover plate stiffener. Since these welds have residual tensile stresses as high as the yield strength, the low stresses introduced by the live loads would place the welds into compression equal to the live load. At best these residual compressive stresses are low. (Fig.1) (3).

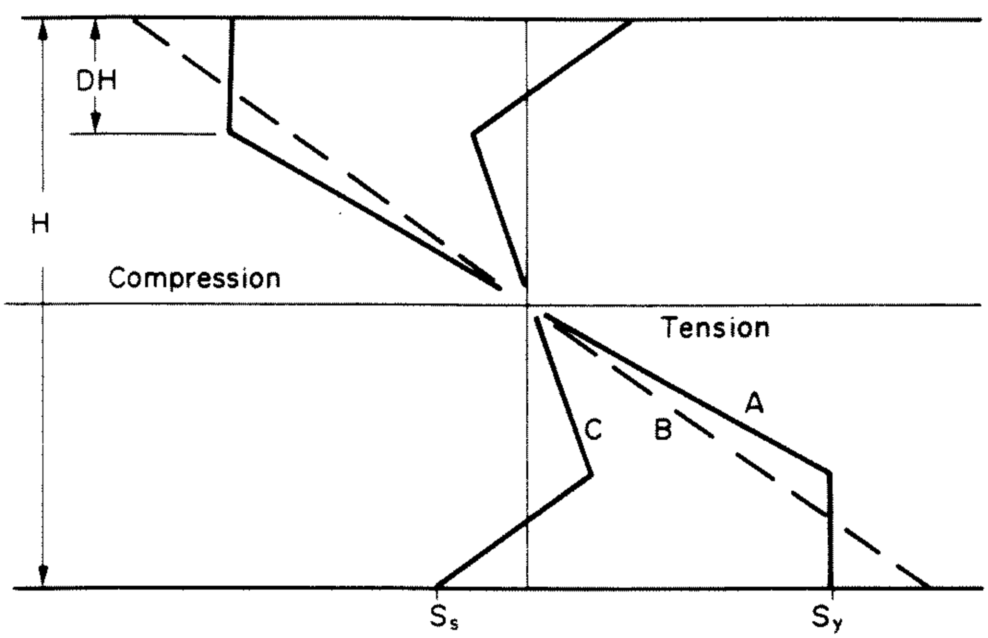

Fig. 1 Stress distribution in a bent rectangular beam
A. Loaded, yielded to depth DH. B. Elastic recovery.
C. Resulting self stress

This would be true for an I-beam with flawless welds. In the real world, flaws such as porosity, slag inclusions, poor fusion or heat checks from grinding can be torn open to create the nucleation site for fatigue cracking under repetitive live loading. Nondestructive testing of these tension welds would have to be performed after the application of the first live load to discover these cracks.

AUTOFRETTAGE

Autofrettage was originally applied to gun barrels by hydraulic pressure or forcing an oversized mandrel through the bore (Fig.2) (3).

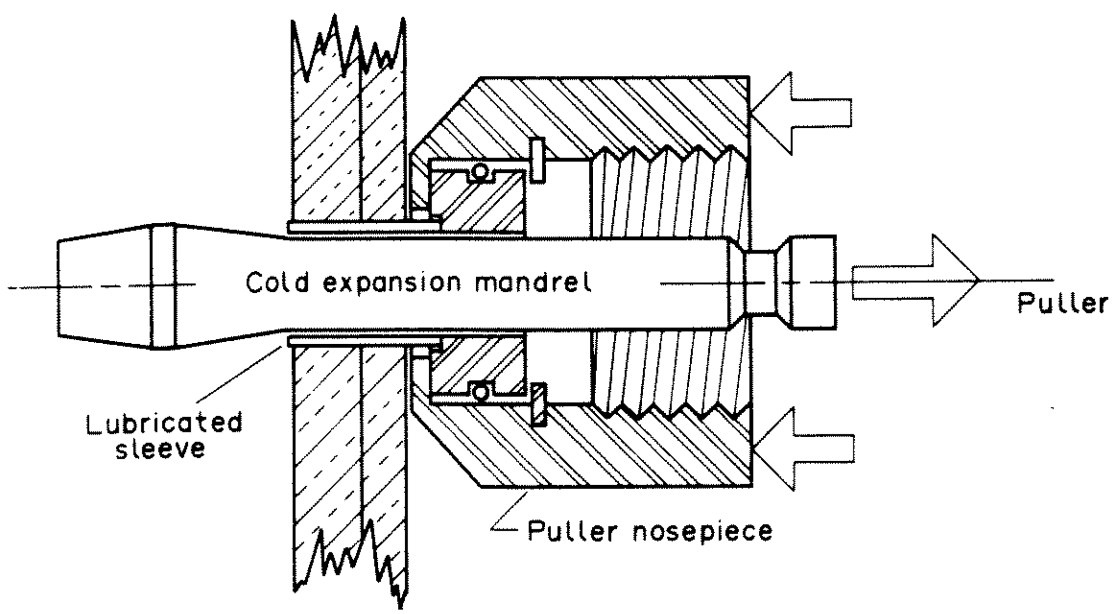

Fig. 2 Schematic of hole expansion.

This method could be applied after drilling holes to arrest existing cracks. A critical review of the location and magnitudes of the balancing tensile stresses introduced by the cold working of the hole bore is important in not moving the crack initiation site elsewhere (Fig. 3) (3).

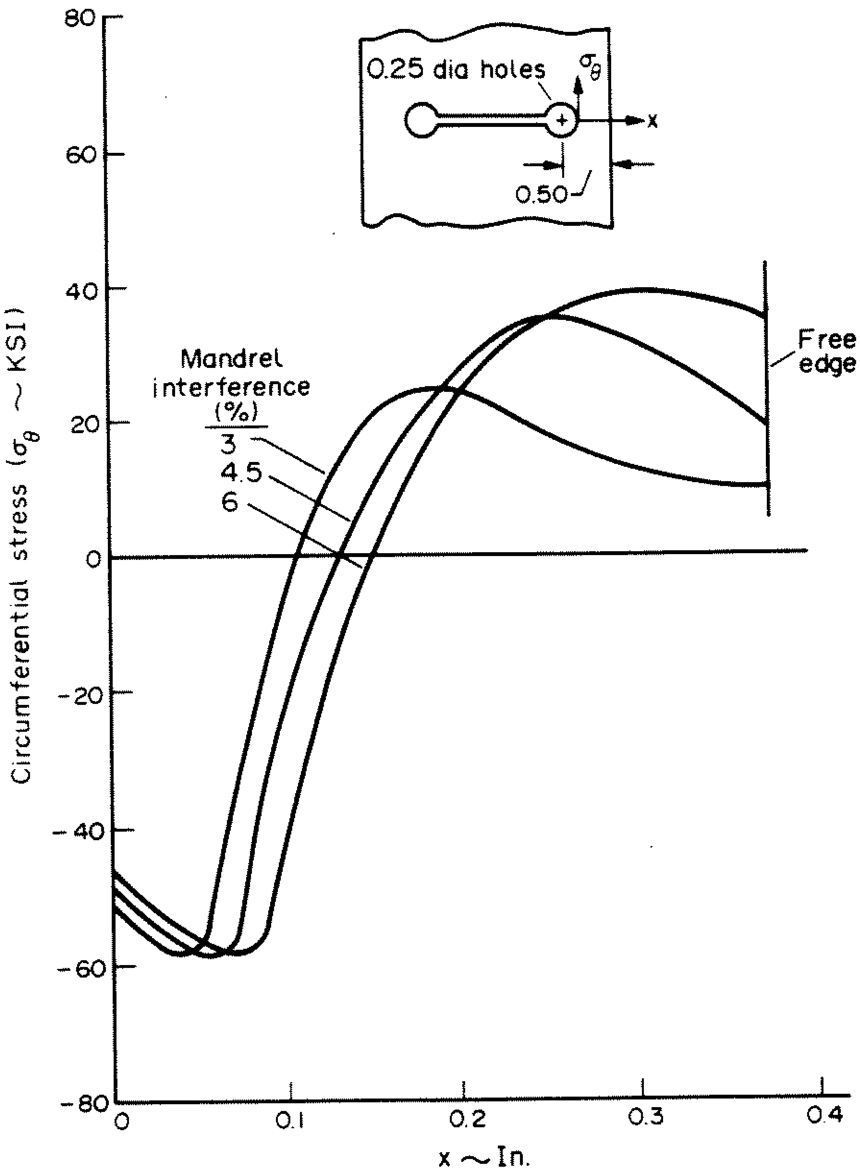

Fig. 3 Self stresses produced by hole expansion

HAMMER PEENING

Welders use manual hammer and pneumatic or electric hammer tools to prevent shrink cracks, lamellar tears, and distortion by peening the intermediate weld passes. The first and last pass may not be peened. The first or root pass may not be peened to avoid hammering through the first shallow weld bend. The last pass and heat affected zone should not be peened, since the compressive stresses introduced by the peening may hide any existing cracks during nondestructive testing (N.D.T.). The N.D.T. is the only check on the welder. Cracks formed due to improper welding practice, i.e. incorrect pre-heat, weld metal and travel must be exposed at this point to initiate corrective action. Hiding these cracks would give the false impression that everything is alright.

The AWS Structural Welding Code, Section D11-92 and the Bridge Welding Code, D15-88 was recently proposed to read as follows:

"When approved by the engineer, peening may be used to mechanically reduce residual stresses created by welding to prevent cracking and lamellar tears. Peening as provided herein shall be done by mechanically striking convex surfaces of intermediate weld beads or layers with a tool that is sufficiently rounded to prevent sharp impressions. Root and final passes shall not be peened, except that when approved by the engineer. Excess weld metal in final passes may be peened provided all of the excess weld metal and all peening marks are removed by grinding.

Unless otherwise approved, a round tool finished to a 1/4 inch minimum radius shall be used. Peening shall be done when the weld is at a temperature of 150-500^{o}F. Care shall be taken to avoid striking fusion boundaries (heat affected zone) of the base metal. Peening energy shall be sufficient to mechanically elongate the surface of the weld without creating overlapping or cracking. Pneumatic tools shall be operated in a manner that prevents contamination of the weld by moisture, oil or other materials."

Peening in the manner described above influences the fatigue strength by insuring the fabrication is free of shrink cracks and lamellar tears. Remember, existing flaws and cracks shorten the fatigue life tremendously. For example, when testing an RR Moore sample to failure at two million cycles, it takes one million eight hundred and fifty cycles to nucleate the crack and only one hundred and fifty cycles for the crack to grow to initiate brittle fracture. So it follows, if weldments are riddled with cracks, the life of the part is only a small fraction of the potential fatigue life of a part free of flaws.

CONTROLLED SHOT PEENING

In addition to, but not in place of, the peening described above, we can introduce a beneficial stress profile below the weldment's surface that will delay crack nucleation and slow crack propagation. A recent proposed revision of the ASME Welding Code UN-39 and AF-234 is considering the following paragraph:

b) Controlled shot peening and other similar methods which are intended only to enhance the surface properties (extend fatigue life and retard stress corrosion cracking) of the vessel or vessel parts, shall be performed after any nondestructive examinations and pressure tests required by the rules. They may be performed after any required post weld heat treatment."

By inducing a layer of compressive stresses below the surface by controlled shot peening, we eliminate high tensile stresses. For example, on a 50,000 ultimate tensile strength material, tensile stresses as high as 35,000 PSI are present from welding and severe grinding. By controlled shot peening this weldment, maximum stresses of -30,000 PSI are achieved. This amounts to a 65,000 PSI surface stress reduction on a 50,000 PSI ultimate tensile strength material. We have learned the fatigue strength is inversely proportional to the magnitude of residual surface stress on a simple bending application. (British Standard).

Selecting to shot peen per Mil-S-13165C (7) specification, we eliminate the variables introduced by other peening methods:

	Mil-S-13165C	Other Peening
Application	Automated	Manual
Shot	Mil-S-851 (2)	None
Intensity	Almen C Strips	None
Coverage	6:11b Fluorescent Tracer	Visual

Mil-S-13165C controlled shot peening insures the results are uniform, repetitive and consistently the best achievable. What's more, by specifying the fluorescent tracer for peening coverage an added control is introduced to insure that the shot peening will provide the fatigue strength improvement we expected. As described under the "peening" section above, fatigue life is drastically cut by the existence of cracks. If any cracks have been hidden by grinding smear or compressive stresses introduced by mechanical straightening, the peening action may expose these cracks (Fig. 4).

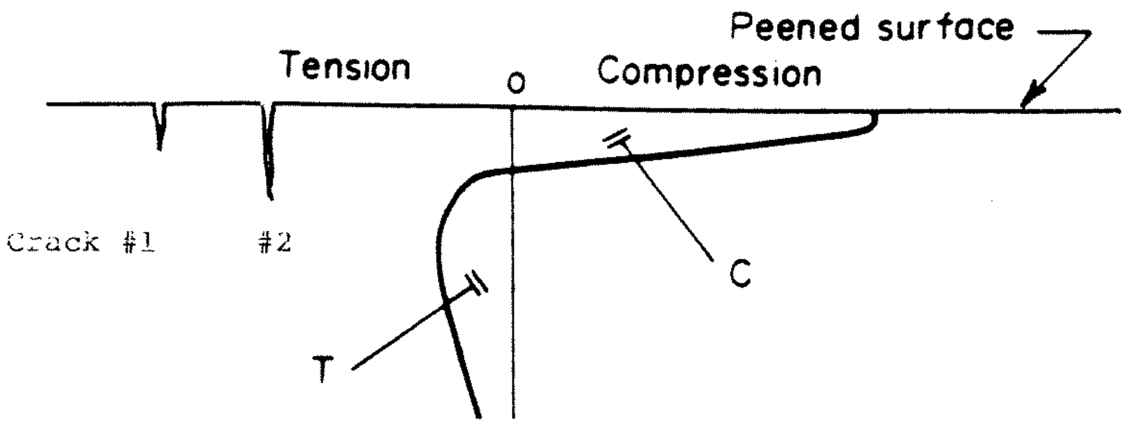

Fig. 4 Stress profile below surface expected on controlled shot peened steel. Crack #1 will remain dormant. Crack #2 will be exposed by fluorescent tracer.

The fluorescent tracer painted on prior to shot peening is checked with a black light to insure the area specified to be peened is totally fluorescent. As the shot strikes the surface, the stretching action causes the tracer to disappear. By checking the area after peening with the black light, we are assured every spot has been cold worked by the shot, if all the fluorescent tracer has been removed. On the other hand, if any tracer is still present, the inspector will circle the spot with chalk and the peening equipment operator will then peen this area until full coverage is achieved. This method was adopted for peening weldments since it exposed flaws deeper than the compressive stresses introduced by the peening. The fluorescent tracer is worked into the flaws by the peening action and is exposed by the black light, similar to a die penetrant N.D.T.

CONCLUSION

This paper discussed various forms of reducing residual stresses citing a few examples. As owners and designers concerned with fatigue, you have the option of selecting the form of stress relief. The common practice on designated new construction is to grind weldments smooth to large radii, to take advantage of a higher stress category. Existing structures with fatigue critical details may not lend themselves to the grinding solution and even new structures may not have that option for one reason or another. Thermal stress relief may not be applicable for the particular steel selected. Peening during welding should be common practice to prevent cracking in the weld itself, while controlled shot peening per Mil-S-13165C and coverage control with the fluorescent tracer per paragraph 6.11b will provide the best level of protection when compared to the other methods alone. A combination of peening, post weld, heat treatment, N.D.T. and then controlled shot peening will give optimum fatigue cracking protection.

REFERENCES

1. Welding Handbook, American Welding Society (AWS) 8th Edition, Copyright 1987.

2. Machinery's Handbook, 23rd Edition, Erik Oberg, Franklin D. Jones & Holbrook, L.Horton 1988 Industrial Press, Inc., N.Y. N.Y.

3. Mechanical Production of Self Stresses, Henry O. Fuchs - Stamford University and James J. Daly, Metal Improvement Company, Inc., Paramus, N.J. - Advances in Surface Treatments, Vol. 4, Page 73-86, Copyright 1987, Pergamon Books Ltd.

4. AWS Structural Welding Code.

5. AWS Bridge Welding Code.

6. ASME Boiler & Pressure Vessel Code

7. Mil-S-13165C.

8. Mil-S-851.