Extending the Fatigue Life of Bridges Using Stressonic® Needle Peening

Sylvain Forgues

The recent tragic collapse of the Minnesota Bridge has reminded us of the importance of quality design, manufacturing and inspection in our daily work. The NTSB will make their full investigation and report, but with the first information relating the accident to corrosion and fatigue cracking, it also raises the question whether a technology such as peening might have been used on this type of welded structure. The Electronics Inc. reference library has over 120 papers on the subject of peening welded structure (www.shotpeener.com/learning/welds.htm). I would like to take this opportunity to look at the advantages of a special technique, called Stressonic® needle peening, to extend the fatigue life of welded metallic structure.

FATIGUE LIFE EXTENSION PROGRAMS

Fatigue life extension programs are common in aerospace for aircraft structure and have been used successfully on almost every major fleet. The first step of a program is to assess the damage at critical locations and decide on which action to take. When light damage is found, it is usually removed and the part strengthened in some way. When damage is too extensive, the part is simply replaced altogether. Repairing damage or replacing a part can be very expensive. The key to such a program is to perform improvements before the onset of significant damage. The approach has to be preventative instead of corrective to minimize costs and maximize benefits. The approach used in aerospace can also be used to extend the life of welded metallic structure.

Peening is one of the best preventative treatments available to increase fatigue life. It is very inexpensive compared to replacing or reinforcing a structure and can extend the life of a part or component multiple times. To improve fatigue life significantly, peening must be performed in the initiation phase of a crack development. When cracks are initiating, the compressive residual stress generated by the peening will slow the crack formation. If crack lengths are beyond the compressive layer, the peening will have little impact. Fortunately, the initiation phase of a crack is usually 2 to 3 times longer than the propagation phase (see Figure 1). This provides plenty of opportunities for applying a peening program.

Studies (Ref.1-2) have shown that by blending the surface and re-peening at fixed intervals, the fatigue life of a component is extended more than with a single peening application. This is the objective of a Fatigue Life Extension Programs whether for aircraft structure or on welded metallic structures used in many bridges.

NEEDLE PEENING WITH STRESSONIC® EQUIPMENT

Because of access constraints, peening the welded structure of a bridge requires small portable equipment that is easy-to-use, generates deep compressive residual stresses and will not leave behind media that can contaminate the environment. Sonats has developed such a machine called the StressVoyager®.

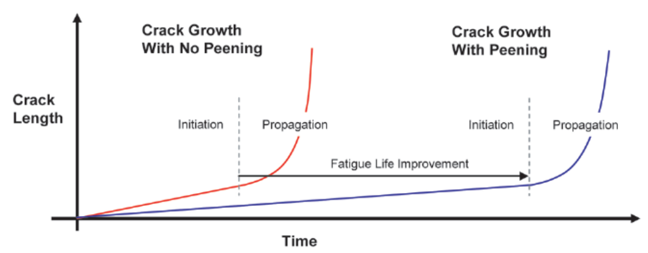

Figure 1. Effect of Peening of Fatigue Life

It uses the Stressonic® process (Figure 2) where electrical energy is transferred to mechanical vibration through a piezo-electric sensor. This sensor vibrates at ultrasonic frequencies (20-40 kHz) but with a very small displacement. The displacement is therefore amplified through a series of boosters to provide useful mechanical movement to needles that perform the peening.

The central unit of the StressVoyager® weighs approximately 44lbs and is often moved around on a small wheeled cart as shown in Figure 3. It requires normal 110V current and

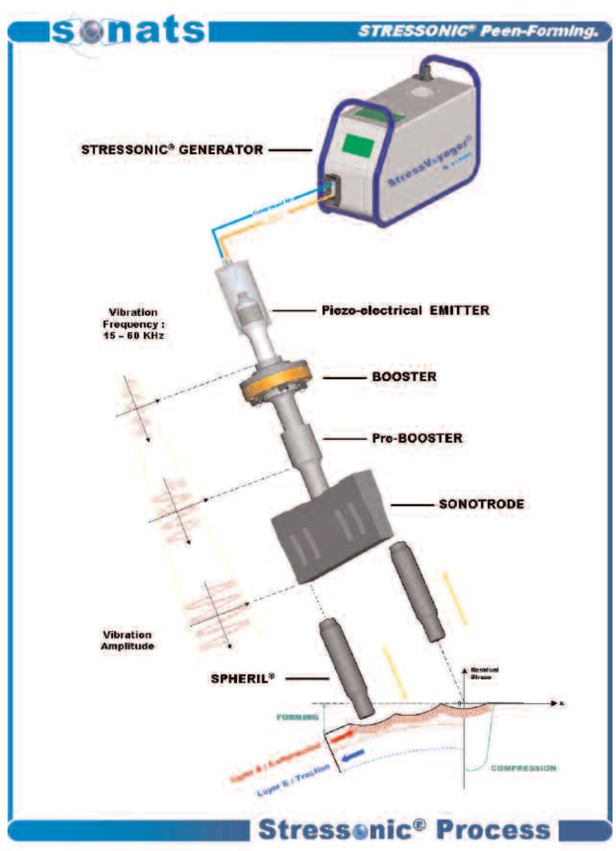

Figure 2. Stressonic® Needle Peening Process

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Figure 3. StressVoyager® for Needle Peening

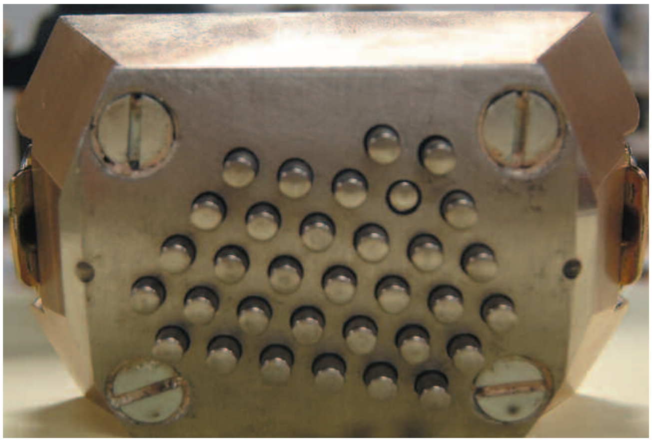

Figure 4. Needle Peening Head

a small quantity of compressed air to cool the peening head. The peening gun weighs roughly 9lbs and feels like a large drill. A needle head is installed at the tip of the gun to do the actual peening (Figure 4). Different sizes of peening needles and head geometries can be used depending on the application. For example, a special angled head has been designed for locations with limited access. The larger needles, also called "spherils", have a diameter of 0.197" and can generate an intensity of 0.028C or more.

FATIGUE RESULTS FOR WELDED JOINTS

A StressVoyager® was used to peen joints representative of welded steel structure (Ref. 3). The needle peening was performed using 0.157" diameter spherils, with a 100% coverage. To achieve optimum benefits and adequate coverage, each weld toe was treated as well as ¾" of the plate on each side of the weld.

The residual stress profile was measured using X-ray diffraction after the needle peening operation. The results can be seen in Figure 5. Results indicate a deep compressive stress level (-45Ksi) at the surface and a total depth of compression of roughly 0.070". This large depth of compression ensures that the needle peening will be effective when cracks initiate.

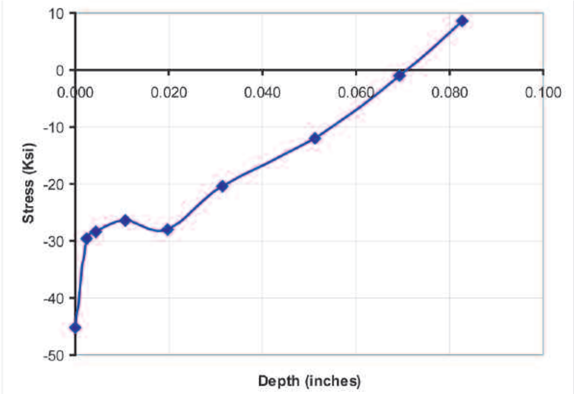

Figure 5. Compressive Residual Stress Distribution Following Needle Peening

Fatigue testing of welded specimens have confirmed the effectiveness of the needle peening process. The fatigue life of the specimens were evaluated both in the "as welded" and the "needle peened" condition. At a delta stress level of 60ksi, the needle peening provides a fatigue life improvement of 15x over the welded condition. This tapers off with higher $\Delta\sigma$ levels, but is even more important at lower stress levels usually seen in bridges.

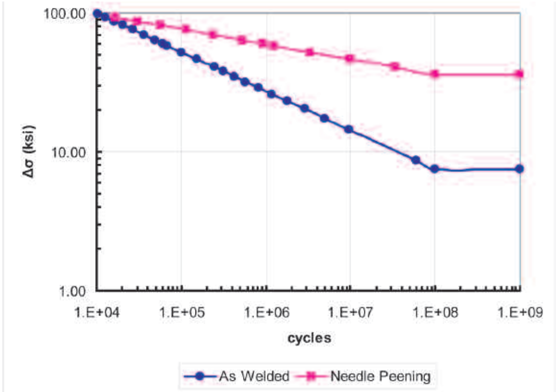

Figure 6. Fatigue Life Comparison of "As Welded" and "Needle Peened" Structure

This fatigue data could also be looked at from a different angle. Federal Highway Administration Statistics (Ref. 4) report a continuous increase in the weight of heavy truck on U.S. roads over the last 35 years. Needle peening can be used to compensate such a weight increase. For a fixed number of cycles, Figure 6 shows that needle peening can withstand a higher stress level. At 10 million cycles, for example, needle peening can withstand a 68% increase in the stress level over welding alone. Using needle peening on bridges would result in an increased level of safety at a very minimal cost.

CONCLUSION

Stressonic® needle peening is a great technique to re-establish or extend the life of bridges and other welded structures. The best and most cost-effective approach is to needle peen the welds during the initial fabrication or as a preventative measure before degradation becomes too significant.

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The StressVoyager® is a clean, easy-to-use and very effective tool to increase fatigue life. Testing of welded structure has shown that it provides deep compressive residual stresses and a significant fatigue life improvement.

Used to either prolong the useful life of bridges or to safeguard against ever increasing loads, needle peening is a cost effective technique to increase the safety of our aging infrastructures.

REFERENCES

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2) Kohls, J.B, Cammett, J.T., Gunderson, A.W., "Effect of Multiple Shot Peening/Cadmium Plating Cycles on High Strength Steel".
3) Bousseau, M., Millot, T., "Fatigue Life Improvement of Welded Structures by Ultrasonic Needle Peening Compared to TIG Dressing".
4) US Department of Transportation, "Comprehensive Truck Size and Weight Study"

Sylvain Forgues has a Bachelor's degree in Mechanical Engineering and a Master's degree in Applied Mechanics where he studied the beneficial effects of coldworking through 3D non-linear finite element analysis, residual stress measurement by x-ray diffraction and experimental fatigue testing. He started his career at Bombardier Aerospace in Research and Development and worked on the Aircraft Structural Integrity Program (ASIP) of the CF-18. After 5 years, he transferred to the commercial side where he was in charge of structural in-service issues for the fuselage of the CRJ-200 fleet. In 2002, he became Section Chief of the R&D, Robotics and Software department at L-3 MAS where his team developed and marketed an on-aircraft robotic shot peening system used on the CF-18 and on the CRJ-700.

Mr. Forgues has more recently formed his own company, Shockform Incorporated, which provides innovative fatigue life improvement technologies to companies in Aerospace, Energy and Transportation sectors. Shockform works with Sonats to market Stressonic® Peening technology in North America.

You may contact Mr. Forgues by phone at (450) 430-8000 or by e-mail to sylvain.forgues@shockform.com. Mr. Forgues will be presenting Stressonic® peening at the next EI workshop in Arizona and will be available for discussion at the Sonats booth #3.

Why bridge welds are important

After the bridge collapse in Minneapolis, hundreds of older steel bridges in the U.S. were carefully inspected. Deserving of particular attention were bridges, like the Minneapolis bridge, that were built in the 1960s with welded joints. Earlier steel bridges were bolted together but welding was cheaper, easier and provided more flexibility in how the pieces could be assembled. However, engineers at that time had a limited understanding of how welded joints endured time and stress.

Research in the 1970s revealed that certain welded components were vulnerable to metal fatigue. The I-35W Minneapolis bridge included these types of welded components in locations that were "fracture-critical", meaning that a break in that spot would probably lead to a collapse. However, engineers can design "redundant" bridges that are not vulnerable to the failure of a single part. Fracture-critical bridges are still being designed and built today, and old bridges with fracture-critical components can be rehabilitated instead of replaced, say civil engineers.[1]

There are more than 750 bridges with steel deck trusses, similar to the I-35W, in use in the United States at this time.

[1]The New York Times, August 4, 2007

UIT process on welds is studied

Considerable research is being conducted on the use of Ultrasonic Impact Treatment (UIT) on welded joints. We've posted one of these papers at www.shotpeener.com by three researchers from the University of Stuttgart, Germany. This paper was presented at the 2005 International Association for the Bridge and Structural Engineering Symposium in Lisbon, Portugal. The summary follows.

Rehabilitation of Welded Joints by UIT

Due to increasing traffic and life, loading fatigue becomes of high relevance in order to maintain the integrity of existing steel bridge structures. Poor construction details which used to be regarded as less important when applied to road bridges are nowadays often the starting point of fatigue cracks. Repair and strengthening of welded details are thus of great importance in order to extend the life time and safety of existing bridges. For welded details under fatigue loading one effective possibility to do this is the application of local post-weld treatment methods. This paper presents the application of a relatively new post-weld treatment method called "Ultrasonic Impact Treatment"(UIT). The paper summarizes the results obtained on a series of experimental fatigue tests where UIT has been applied in order to extend the life time of partially damaged non-load carrying fillet welded joints.

(For complete paper, go to www.shotpeener.com)