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Innovative **impact treatment**
surface solutions

Fatigue life improvement of welded structures by **Ultrasonic Needle Peening**

Technology Division of Europe Technologies

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1. Abstract

Conventional Hammer Peening is a well-known post-weld treatment for fatigue life improvement. This method is applied to the weld toe only.
Ultrasonic Needle Peening (UNP) (also called Ultrasonic Impact Treatment (UIT) or High Frequency Mechanical Impact (HFMI)) is a process achieving the same effect, but with much process control compared to conventional needle peening. UNP is also faster and far less harmful for the operator. Moreover UNP process can be used by any operator after only one day of training. For these reasons many industries have shown a strong interest for this innovative technology.

This document describes SONATS research, in-field experiences and knowledge about Ultrasonic Needle Peening. It is dedicated to any people (Engineers, welders, operators, controllers) who are interested in this process.

NOTE: Many designations are used to describe the process which consists in using high frequency mechanical vibrations to put in movement impactors or needles to throw against the metal surface area to be treated:

- *UIT for Ultrasonic Impact Treatment,*
- *UNP for Ultrasonic Needle Peening,*
- *UP for Ultrasonic Peening,*
- *or HFMI for High Frequency Mechanical Impact treatment).*

In this document we will, most of time, use "Ultrasonic Needle Peening" or "UNP".

Figure 1 : SONATS StressVoyager® UNP System

2. UNP Effects

According to P. J. Haagensen and S. J. Maddox[1], "The weld toe is a primary source of fatigue cracking because of the severity of the stress concentration it produces". For this reason, the weld toe can be considered as a "notch".

Hammer Peening or Needle Peening is an ancestral process, which consisted in striking manually a weld by the means of a hammer, to improve its surface finish and resistance. Later, pneumatic and magnetostrictive tools have been developed to help the operator. Nowadays, the principle is still the same but the equipment design has been improved. The latest technologies are using piezo effect for electrical to mechanical vibration. The vibrating element, named Sonotrode, is then use to provide the kinetic energy to a needle (or impactor). Thanks to those modern tools, the influence of the operator on the process application is close to zero, with little efforts and high treatment speed.

Research about UNP started in the late fifties[2] and sixties in the USSR [3] [4] [5]. Extensive research have been carried out later in the nineties, on structural steels [6], high strength steel and aluminum [7] [8], showing each time a high level of improvement in term of fatigue life. In 1996, the International Institute of Welding published a specification [9] and in 1999 the first "Guide for application of UIT" [10].

On this basis, many industries started to pay attention to this effective and user-friendly post-weld improvement techniques.

The weld toe improvement methods rely on two main principles:

- Weld toe geometry modification,
- Residual Stresses Modification.

Ultrasonic Needle Peening acts on both phenomenon to finally achieve high level fatigue life improvement of the treated welded detail.

2.1. Modification of the weld toe geometry

Conventional methods of post weld treatments, such as TIG dressing or weld toe grinding consist of increasing the radius at the transition between the base material and the weld seam. UNP achieved the same effect by the mean of high frequency impacts, able to induce local deformation, and creating a controlled groove at the weld toe.

The following picture presents the geometry modification after UNP/UIT compared to "as welded" or other post treatment methods.

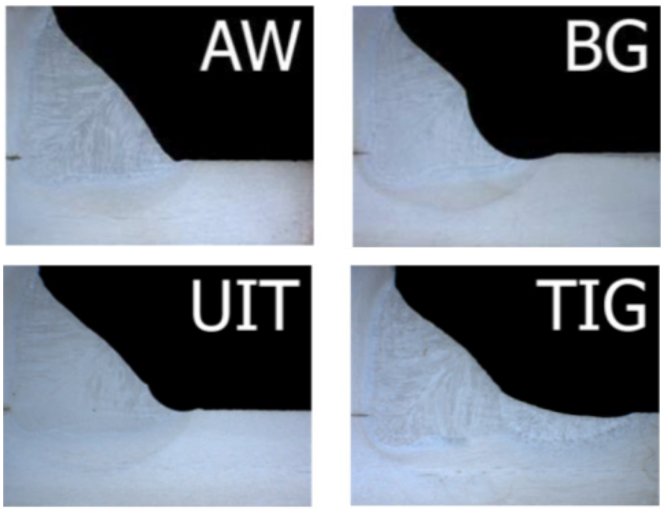

Figure 2: Image illustrating weld to geometries for "as welded" condition and after post treatment (burr grinding UIT and TIG dressing)[11]

The treatment should be applied uniformly all along the weld toe without any discontinuities. The groove created by successive impacts can be represented as following.

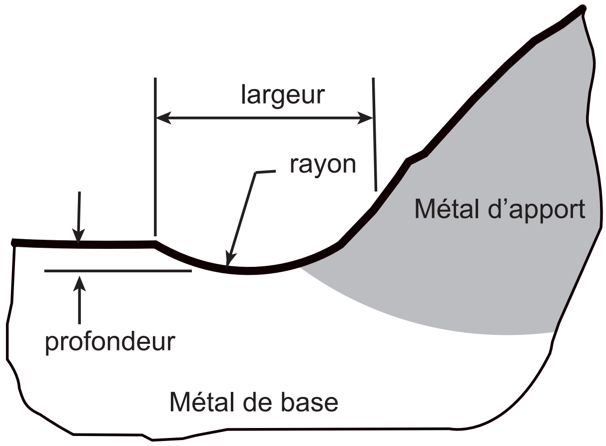

Figure 3: UNP groove scheme

Results observed in the literature, present a wide range of groove sizes. Galtier and al[12] measured after UIT on 2 steel grades, radii from 0.8mm to 2.0mm and depth from 0.17mm to 0.4mm.
Yildirim & Marquis [13] studied the effect of several HFMI tools, the radii were measured from 1.80mm to 4.55mm, Width from 2.39 to 5.45mm and Depth from 0.16mm to 0.29mm.

Another study carried out by Yekta and Al[14] shows the following groove sizes for one equipment with several different peening treatment times.

Mesure géométrique du cordon de soudure.

Groupe (mm)	Rayon		Profondeur de soudure (Face extérieur du métal de base)		
	x (mm)	s (mm)	x (mm)	s (mm)	max. (mm)
B	1.76	0.36	0.16	0.04	0.19
C	2.09	0.18	0.16	0.06	022
D	1.17	1.09	0.17	0.15	039
E	1.69	0.27	0.36	0.40	1.10
F	2.37	0.11	0.27	0.07	0.37

Note : x=moyenne, s= écart type

Figure 4 : Radius (from 1.17 to 2.37 mm) and Depth (from 0.16 to 0.36mm) according to several peening conditions 14

All geometries presented in these 3 studies lead to a high level of improvement in terms of fatigue life, by using different UNP equipment, treatment procedure and on several materials.

In 2013, Marquis and Barsoum[15] compiled 46 studies from the last decade to create procedures and quality assurance guidelines about the UNP process. In this document, we can read “The HFMI indentation depth following treatment should be 0.2–0.6 mm while the resulting width is typically 2–5 mm”.

NOTE: These values are given as typical geometries; it results from a complete coverage of the weld toes by impacts (also called 100% coverage).

2.2. Compressive residual stresses

The second effect of Ultrasonic Needle Peening is the introduction of beneficial compressive residual stresses. Depending on the tool, intensity of the treatment and material, the level of introduced compression can vary.

The following graph presents residual stress profiles obtain after treatment by UNP equipment on S355 ; several set up conditions have been characterized. These measurements have been performed by XRay diffraction at SONATS Laboratory (Carquefou, France).

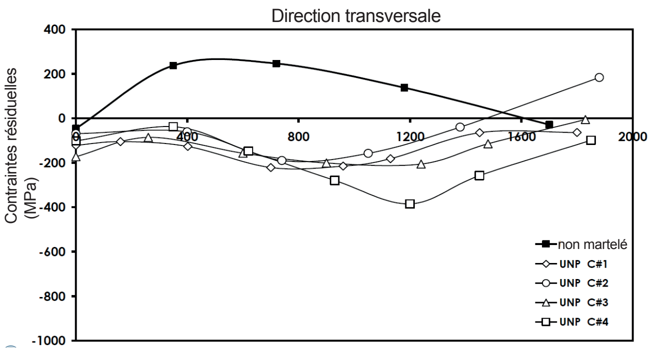

Figure 5: Residual stress distribution (transversal direction) at the surface and into depth, weld toe location

The red curve corresponds to “As welded” specimen, high tensile residual stresses is observed down to 1.6mm.
After UNP, we observe high compressive residual stresses down to more than 1.4 mm for all conditions. As for shot peening (or Ultrasonic Shot Peening), compression introduced is beneficial for the fatigue life, acting against the service loads.

Yildirim & Marquis [13] observe similar results, “tensile residual were found at all of the weld toes measured. Values ranged from +185 to +552 MPa. For the HFMI-treated specimens, compressive residual stresses were measured in 31 of the 32 HFMI grooves studied prior to fatigue testing. The single HFMI groove which showed tensile residual stress had a value of only 52 MPa. The compressive residual stresses before fatigue testing were −53 to −457 MPa for the high-strength steel specimens. ”

Following this investigation, authors conclude that UNP imparts compressive stresses in weld toes being treated for all the tested equipment’s.

3. Process parameters

The UNP/UIT/HFMI process is monitored by several parameters, influence of these parameters are discussed in this paragraph.

3.1. Mechanical Vibration frequency and Needle Impact frequency

On an Ultrasonic Peening system, a high voltage electrical signal is created by an Ultrasonic Generator. This signal is then converted to a mechanical vibration at the same frequency, either by a piezo-electrical converter or a magnetostrictive converter.
When the Needle (or Impactor) is in contact with the vibration surface, it gains kinetic energy and is thrown against the part to be treated. Then the needle moves back to the vibrating surface for the next cycle.
Therefore the Mechanical Vibration frequency and the Needle Impact frequency should be dissociated.

The following scheme presents the acoustic elements and the impactor location:

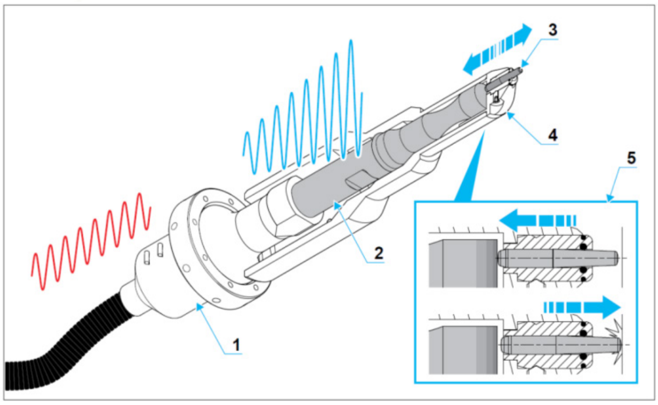

Figure 6 : Acoustic elements inside the UNP peening head (SONATS)

With:
1. Piezo-electrical converter
2. Sonotrode
3. Specific Impactor (Or Needle)
4. End piece (to guide the Impactor)
5. This little scheme illustrates the movement cycle of the impactor inside the end piece

Influence on the results:
The ultrasonic vibration frequency of the sonotrode is the same as the converter but the impactor is uncoupled from the Sonotrode (therefore the impact frequency is lower than the ultrasonic frequency). By pressing the tool on the weld toe, the operator forces the needle to come in contact with the vibrating sonotrode, to finally strike the weld toe with a lower frequency than the vibration frequency of the sonotrode.

For SONATS equipment, the ultrasonic vibration frequency is 20 KHz with an impact frequency about 220Hz (based on measurements done by counting impacts on steel plates). The impact frequency depends on the pressure applied by the operator, the amplitude of vibration, the needle geometry, the material and the travel speed along the toe.

Figure 7[17] presents the first equipment developed by E.O. Paton Welding Institute (Ukraine) which worked at 27 KHz.

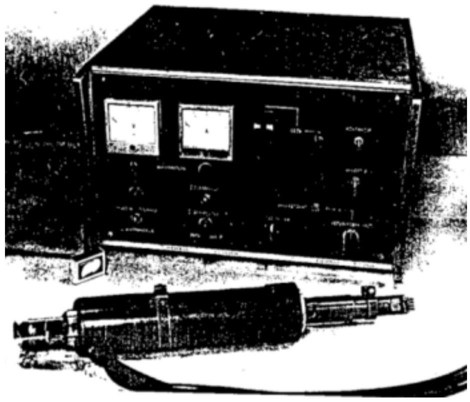

Figure 7 : First UIT tool developed by E.O. Paton Welding Institute (Ukraine)

Later, this tool has been used for many fatigue test programs on laboratory specimens and real structures, showing each time attractive fatigue life improvement [6 7 8 9 10 12 14 15 26]. E S Statnikov explains in [18], that 27 KHz equipment produces impacts at 80 to 200 Hz. This impact frequency is similar to SONATS equipment' observation.

According to Y. Kudryavtsev, a 20 KHz piezo-electrical equipment has been developed in the early 90'. Fatigue test results show similar fatigue life improvements as for magnetostrictive 27 KHz equipment [19 20 21].

In 2013, IIW carried out a round robin test comparing the fatigue life improvement achievable by different HFMI (High Frequency Mechanical Impact Treatment) including 27 KHz equipment, 20 KHz equipment and low frequency (< 1KHz) pneumatic tools[13]. Longitudinal non-load carrying welded specimens have been treated by HFMI. Samples were fatigue tested under axial loading. Fatigue test results indicate that all of the HFMI-improved welds using equipment with 3 frequency of vibration (27 KHz, 20 KHz and <1000Hz) satisfied IIW requirements (FAT160 and m1=5).

This round robin test and previous studies clearly show that the vibration frequency has no influence on the fatigue life improvement generated by UNP/UIT process. Important parameter is the frequency of impact, and its reproducibility.

A smooth and complete continuity of groove should be produced by operator on the weld toes. Thanks to its consistent peening impact frequency and amplitude, SONATS equipment allows a much quicker process without harmful conditions for the operator. Low frequency pneumatic tools suffer from a lack of control on impact frequency and amplitude, and induce harmful peening conditions which make difficult for an operator to achieve a bright and continuous groove.

3.2. Amplitude of vibration

A vibration is defined by its frequency and its amplitude. Usually, when the frequency of vibration increases, the amplitude decreases. SONATS StressVoyager® UNP equipment is able to work in the range of 10µm p/p to 60µm p/p.

The Figure 8 below presents the sinusoidal ultrasonic wave.

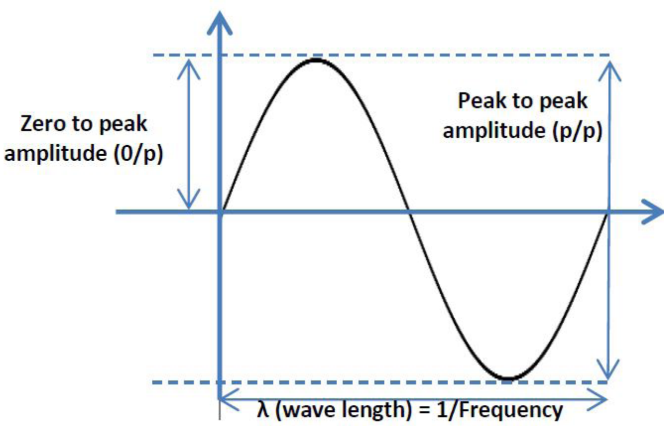

Figure 8 : Sinusoidal wave

The high level of energy to treat the weld toe is obtained thanks to small displacement at really high speed, inducing a high acceleration of the impactor. Small amplitude is user friendly compared to high amplitude obtained at low frequency by pneumatic equipment (several millimeters of displacement).

The amplitude of vibration should be easily modified depending on the material to treat. To achieve IIW requirements (groove size), SONATS usually uses the following amplitude of vibration:

Frequency	20 000 Hz		
Material	Steel	Aluminum	Stainless Steel
Amplitude (p/p)	30 – 60µm	20 - 40µm	20 – 40µm

Table 1 : Typical sonotrode's amplitude of vibration for SONATS StressVoyager® UNP equipment

SONATS performed fatigue test with 60 µm p/p amplitude achieving high level of fatigue life improvement[16]. André Glatier and Al [12], used an amplitude of vibration of the sonotrode equal to 40 µm p/p to treat High Strength Steel, the fatigue life of the T-Joint specimen is more than twice than "as-welded" .

The amplitude of vibration is not considered as a key parameter in a large majority of publications. Thus the influence of this parameter on the fatigue life improvement has not been studied. Even if the influence of the amplitude is small with respect to the fatigue life improvement, it has a real influence on the treatment speed and equipment drivability, and therefore on the groove continuity and quality. For this reason, a perfect control of the vibration amplitude of the sonotrode is really important.

3.3. Ultrasonic Needle Peening Power

Some studies talk about the power consumption of the ultrasonic equipment. It's a consequence of several parameters which are:

- Converter technology (Piezoelectric or Magnetostrictive)
- Design and Manufacturing quality of the equipment
- Pressure applied by the operator on the tool
- Material to be treated
- Amplitude of vibration

Depending on these parameters the effective equipment power consumption can be multiplied by 10 to achieve identical fatigue life improvement.

SONATS equipment power consumption ranges from 10 watts (without loads) to 150 watts (during the treatment), this low energy consumption comes from piezo electrical converter which is very efficient compared to magnetostrictive transducer. For magnetostrictive transducers, a majority of electrical power is converted into heat, that is why water cooling is necessary.

For piezo electrical converters which are more efficient, the electrical power is mainly converted into mechanical vibration which is then transmitted to the weld toe. Air cooling is sufficient.

The power consumption of the equipment is a consequence of the parameter listed before; it has no particular signification on the quality of the UNP treatment.

3.4. Geometry and diameters of impactors/ needles

Impactors also called needles or strikers are usually made of hard steel.

The peening head is usually composed of 1 to 4 impactors (depending on the supplier). SONATS proposes 3 types of nozzles for its PM03 peening head which are presented below.

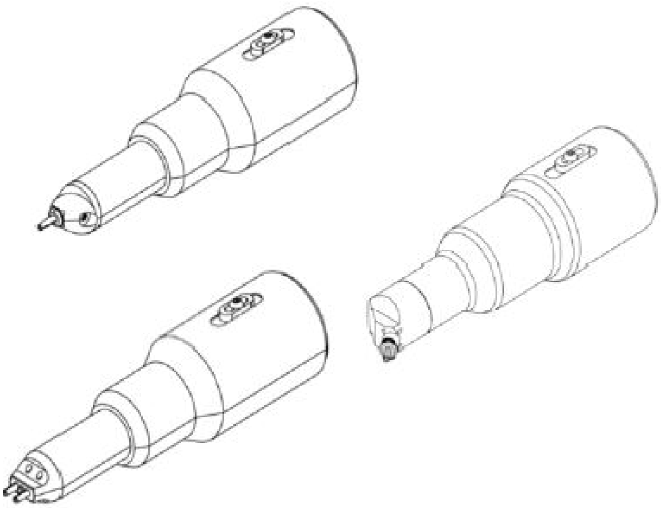

Figure 9 : 1 Impactor, Angled 1 Impactor and 2 Impactors-in-line nozzle for UNP application (SONATS)

To perfectly control the weld toe treatment, SONATS advices to use only 1 needle. The number of impactors has no influence on fatigue life improvement[16]. 2-impactor-in-line nozzle could be use in the case of a perfect quality weld seam and for peening extremities. Angle nozzle is very efficient for treating difficult access toes.

The diameter of the impactors is usually between 3 to 4 mm with 1.5 to 3 mm impact tip radius.

SONATS proposes 2 geometries of impactors as presented after on Figure 10. Thanks to these 2 needle types, every acceptable geometry can be treated on every material. These needles are made of 100C6 bearing steel. To treat stainless steel or titanium, specific needles can be used.

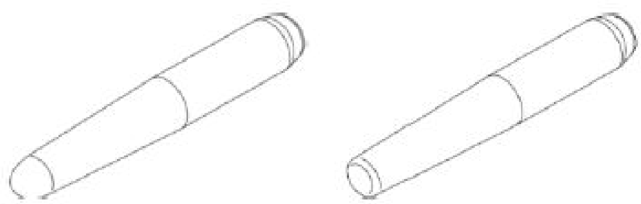

Figure 10 : 1.5 mm radius impactor and 3.00 mm radius impactor (SONATS)

4. Fatigue Recommendations

These paragraphs detail the UNP process recommendations according to International Institute of Welding (IIW), classification societies, and professional associations on transportation infrastructures.

4.1. IIW recommendations

With respect to Post Weld Treatment Methods, the following document is considered as reference worldwide:

"IIW Recommendations on Post Weld Fatigue Life Improvement of Steel and Aluminium Structures" [22]

This document has been created in order to standardize the optimum application methods for burr grinding, TIG dressing, hammer peening and needle peening. It is also including design resistance curves based on both nominal stress assessment method and on the structural hot-spot stress method. This IIW guideline does not take into account Ultrasonic Needle Peening method yet. However, in 2013 IIW published a set of 2 complementary documents called:

- Fatigue strength improvement of steel structures by high-frequency mechanical impact: proposed procedures and quality assurance guidelines15.
- Fatigue strength improvement of steel structures by high-frequency mechanical impact: proposed fatigue assessment guidelines [23]

SONATS strongly advises anyone interested in UNP process, to read these 2 documents.

According to IIW, any supplier which fulfills "The proposed procedures and quality assurance guidelines" can guaranty X1.6 Improvement Factor of the fatigue limit, it corresponds to a 4-Fatigue class increase (for steels fy <355 MPa). The fatigue class improvement increases with the strength as shown in Figure 11. This guideline gives additional improvement factors to take into account thickness, steel strength and loading effects.

As one could see on Figure 11, for steels with fy >950 MPa, more than 8 FAT classes could be won.

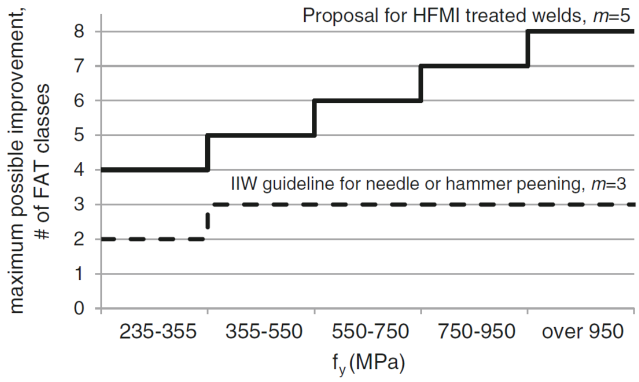

Figure 11 : Proposed (by IIW) maximum increase in the number of FAT classes as a function of the Steel strength

4.2. Classification societies approaches

Most of classification societies have already acknowledged the benefits of Ultrasonic Needle Peening methods under certain conditions. This paragraph briefly presents recommendations and guidelines about UNP.

4.2.1. American Bureau of Shipping – ABS

The American Bureau of Shipping has updated in 2014, a document called "GUIDE FOR THE FATIGUE ASSESSMENT OF OFFSHORE STRUCTURES (APRIL 2003) [24]". In this document we can read:

"The finished shape of a weld surface treated by ultrasonic/hammer peening is to be smooth and all traces of the weld toe are to be removed. Peening depth below the original surface is to be maintained at least 0.2 mm. Maximum depth is generally not to exceed 0.5 mm.

Provided these recommendations are followed, when using the ABS S-N curves, **a credit of 2 on fatigue life** may be permitted when suitable toe grinding or ultrasonic/hammer peening are provided. Credit for an alternative life enhancement measure may be granted based on the submission of a well-documented, project-specific investigation that substantiates the claimed benefit of the technique to be used.”

4.2.2. Lloyd’s Register –LR

The following table presents the post-weld methods (including UNP) improvement factor according to Lloyd’s registers.

Table 2.4.5 Fatigue strength improvement factors

Method	Improvement factor on fatigue life, f_L	
Weld toes (*see* Notes 1 to 7)		
Disc toe grinding	1,1	
Burr toe grinding	2,0	
TIG and plasma dressing	2,0	
Full burr grinding (toe burr grinding with smooth concave weld profile, *see* Fig. 2.4.5)	3,0	
Hammer peening	1,3	
Controlled shot peening	2,0	
Ultrasonic peening (UP) and Ultrasonic Impact Treatment (UIT), *see* Note 7	2,5	minimum yield stress < 315 N/mm²
	3,5	minimum yield stress ≥ 315 N/mm²
Free edge of parent material (*see* Notes 2, 4 and 8)		
Removal of plate corners, *see* Note 8	1,6	Plate thickness, $t \leq 22$ mm
	1,0	Plate thickness, $t \geq 66$ mm
	Obtain by linear interpolation	66 mm > t > 22 mm

NOTES

1. Fatigue strength improvement factors may only be applied to as-welded transverse butt welds, as-welded T and cruciform welds and as-welded longitudinal attachment welds, *see ShipRight Fatigue Design Assessment Level 3 Procedure*, Table 7.2.1 in Chapter 7.
2. *See* Ch 2,2.1.2 for conditions of application of fabrication stage fatigue strength improvement methods.
3. When a factor improvement factor of above 1,6 is applied to the weld toes, full penetration welds are to be used to eliminate the possibility of cracking at the weld root. For a lower improvement factor, partial penetration welds in accordance with the *Rules for Ships* may be used. *See* 2.4.2.
4. In way of areas prone to mechanical damage, fatigue improvement may only be granted if these are adequately protected.
5. No improvement factor should results in a fatigue life longer that that calculated using the S-N curve given in Table 2.4.7.
6. Treatment of inter-bead toes will be necessary for large multi-pass welds. *See* 2.4.3, 2.4.4 and 2.4.6.
7. UP and UIT may only be used on single pass electro-gas butt welds for plate thickness in the range from 50 mm to 80 mm.
8. Improved factors may be applied in addition to the improved free edge S-N curves given in Table 7.1.1 in Chapter 7 of *ShipRight Fatigue Design Assessment Level 3 procedure*.

Table 2 : Improvement factor of fatigue life for several post-weld improvement methods (including UIT) according to Lloyd’s Register

4.2.3. Bureau VERITAS

The following recommendation is presented in BV document “Rules for the Classification of Offshore Units “ [26]

Article 2 Post welding treatment

2.1 Scope

2.1.1 General
In normal design and building conditions, post welding treatments are not applied.

The decisions to apply a post welding treatment may be required for specific hot spots, on a case-by-case basis, where the damage ratio is closed to the limit and in case of repair.

2.1.2 Conditions of application
Full penetration welding is to be adopted. Post welding treatment of partial penetrations is not accepted.

The post welding treatment procedure is to be performed according to a recognized standard and approved by the Society.

2.1.3 Mechanical post welding treatment
The following mechanical post welding treatments are accepted:

- grinding
- shot peening
- needle peening
- ultrasonic peening .

In principle, hammer peening is not accepted.

2.1.4 Thermal post welding treatment
The following thermal post welding treatments are accepted:

- TIG refusion
- plasma refusion.

Figure 12 : Accepted Post welding treatment by Bureau VERITAS

2.3 Fatigue resistance assessment

2.3.1 General
These treatments improve the weld toe and the residual stresses leading to an increase of the S-N curve class.

The post weld S-N curve may have a different slope than the as welded S-N curve.

2.3.2 Assessment
The fatigue lifetime of the treated details is to be assessed taking into account the modified S-N curves. The used S-N curves are to be duly justified, by fatigue tests or by a recognized standard.

2.3.3 Experimental S-N curves
When tests are considered to determine the S-N curve, the test program has to be approved by the Society.

Attention is to be paid to the necessary number of samples, and the distribution of the results along the stress range axis to allow a correct determination of the S-N curve slope and standard deviation.

To be homogeneous with the Rules for as welded joints, the design curve will correspond to a curve, at minus 2 standard deviations, and taking into account confidence intervals of the calculated mean and standard deviation.

Figure 13: Fatigue assessment procedure

4.3. American Association of State Highway and Transportation Officials (AASHTO) and Federal Highway Administration (FHWA) Recommendations

In United States of America, as in Europe or in Japan, some existing welded bridges are prone to fatigue failure. The US Federal Highway Administration (FHWA) estimates that $76 billion are necessary to repair deficient bridges across the United States. For this reason, in 1996 the FHWA decided to study the “Post-Weld treatment of a welded bridge girder by Ultrasonic Impact Treatment” [26] , this process has been judged as very competitive compared to conventional methods, to extend the fatigue life and reduces the maintenance costs of existing welded bridges. Later, Pr.Roy and Pr.Wright from Lehigh University, experimentally investigated the fatigue performance bridge girders with welded girders and cover plates. Medium strength steel and high strength steel have been tested with several combinations of cover plates welding configurations. The conclusion of this study was for a large majority of specimens, failure located at the weld toe of the cover plates, with 1 to 4 category detail improvement according to AASHTO. This recommendation is presented in the following document:

"AASHTO LRFD Bridge Construction Specifications - Second Edition 2004 (2008 Interim Revisions)"

5. Results with SONATS UNP equipment

5.1. Published studies

SONATS has a 20 years' experience in research for impact surface treatment activated by ultrasounds. Most of these research programs have been conducted under confidential agreements with end-customers.

This paragraph presents some published papers with respect to SONATS Ultrasonic Needle Peening equipment.

5.1.1. Fatigue Life Enhancement of Welded Structures using STRESSONIC® Ultrasonic Needle Peening [16]

The French Institute of Welding, in collaboration with SONATS, conducted a study aimed to evaluate Ultrasonic Needle Peening process capability to increase the fatigue life of welded components. The results of this study have been presented at ICSP11 Conference (Indiana, USA - 2011).

EXPERIMENTAL PROGRAM:

Specimens were T-Joint made of S355J2. The geometry is presented below in Figure 14.

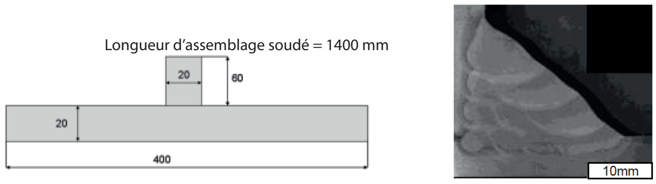

Figure 14 : T-joint geometry and micrograph illustrating the multi-pass

Specimens were then needle peened by SONATS according to 4 combinations of parameters presented in the following table. Figure 15 shows a picture of the equipment in process.

Parameters	C#1	C#2	C#3	C#4
Needle quantity	3	3	1	1
Needle type (tip radius)	S3-15 (3mm)	S3-13 (1.5mm)	S3-15 (3mm)	S3-13 (1.5mm)
Amplitude of vibration	60 µm p/v	60 µm p/v	60 µm p/v	60 µm p/v
Travel velocity	8mm/s	8mm/s	8mm/s	8mm/s
Shifted Pass quantity	2	2	2	2

Table 3 : Treatment parameters

Figure 15 : Ultrasonic needle peening of the weld toe

Each specimen has been fatigue tested using a 4 points bending machine with stress ratio R=0.1 and 20Hz sinusoidal signal. Additional specimens have been produced for residual stress measurements done by X-Ray diffraction and roughness measurements with a 2D profile-meter. 45 specimens have been fatigue tested (9 unpeened and 36 peened).

RESULTS:

As expected, the Ultrasonic Needle peening treatment has created a plastic deformation of the weld toes by generating a groove along the weld toe. For each combination of parameters residual compressive stresses are observed as shown in Figure 16.

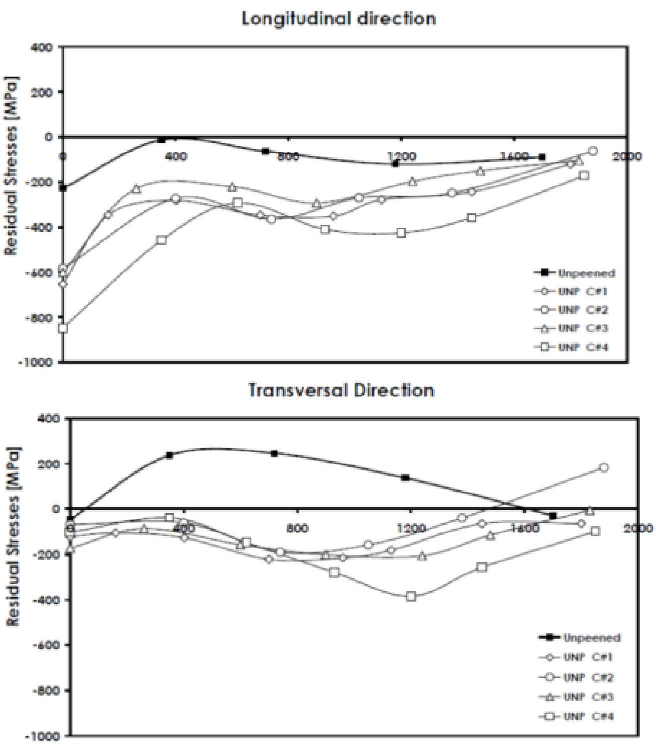

Figure 16 : Residual stress profiles in the longitudinal and transversal direction for as welded and UNP specimens

For each combination of parameters, fatigue life improvement is observed compared to as welded results as shown in Figure 17.

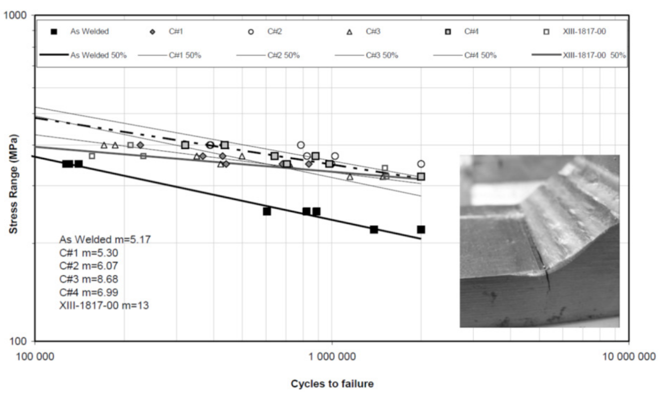

Figure 17 : Fatigue test results for as welded, UNP treated specimens and IIW publication [28]

	As Welded	XIII-1817-00 As Welded	XIII-1817-00 UIT Set2-5mm	C#1	C#2	C#3	C#4
Median	206	188	314	279	319	305	316
Caracteristic curve	197	167	286	251	291	291	298

Figure 18 : Stress range at 2e6 cycles

The results show an improvement up to 50% in stress range at 2 million cycles. Fatigue life was increased at least by a ratio of 3 and up to 5 for 350Mpa stress range. The UIT condition, set 2 from study XIII-1817-00, has been used for comparison and validation of current work. Between both studies results are found comparable. Whatever parameter sets, we still observed a significant enhancement for all specimens. This demonstrates the low influence of varied parameters such as needle radius and needle quantity.

5.1.2. Fatigue behavior on HF hammer peened longitudinal attachments[29]

The objective of this study is to evaluate the fatigue strength of UNP on longitudinal attachment welded joints in bending with a stress ratio R = 0.1.

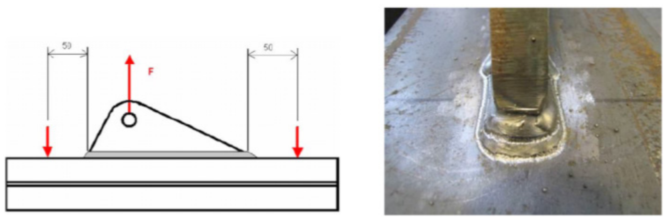

Figure 19 : Specimen geometry and treated weld toe

Six improved specimens were tested at a load level fixed and one as-welded. The results were compared with precedent studies on the same specimens with different weld improvements.

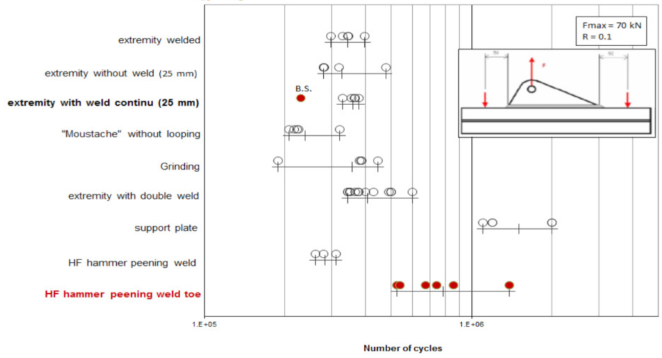

Figure 20 : Fatigue life time observed on longitudinal attachment for different Post-weld treatment including UNP (by SONTAS)

As illustrated on Figure 20, if one compares HF Hammer peening (SONATS) results with “as-welded” results, we observe a mean life time equal 740.000 cycles for UNP and 320.000 cycles for “as welded” specimens. It corresponds to a 2.3 fatigue life improvement factor.

5.1.3. Fatigue life improvement of welded structures by Ultrasonic Needle Peening compared to TIG dressing[30]

Two improvement techniques were studied:

- TIG dressing
- Ultrasonic Needle Peening

These post weld treatments are intended in new structures to increase the fatigue strength and also for post repair operations or upgrading of existing shipbuilding structures.

EXPERIMENTAL PROCEDURES:

The material considered in this work is a hot rolled S355 NL, grade widely used in surface shipbuilding by DCNS.

The plate’s dimensions are 3000 mm length, 700mm width and 12 mm thickness. Figure 21 presents the geometry of the specimen before machining.

Figure 21: Non-load carrying attachment welded on 12 mm thickness plate

The weld is then treated by SONATS (see Figure 22) before machining of the fatigue specimens.

Figure 22 : Ultrasonic Needle Peening equipment and operation by SONATS

Specimens after machining are rectangular plates (400mm length and 80mm width)

Fatigue tests were conducted, on TIG and UNP treated specimens, under axial loading on electrohydraulic machines at 5-10Hz in function of the maximal stress applied.

RESULTS:

Residual stress measurement was performed in the UNP treated area (See Figure 23)

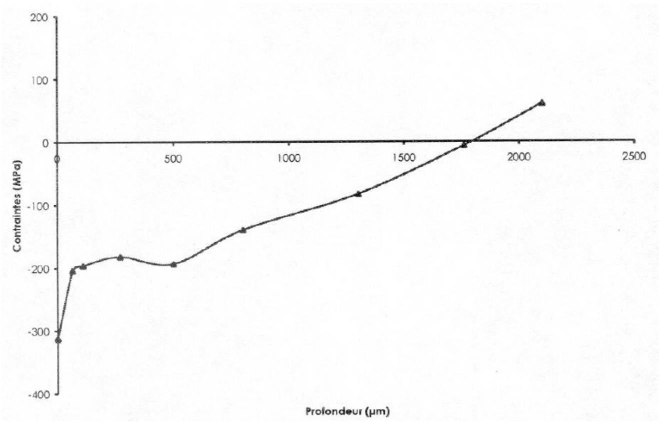

Figure 23 : Residual stress measurement by XRay diffraction

Residual compressive stresses are observed in depth up to 1.7mm after treatment by UNP.

Figure 24 summarizes the Δσ-N curves at 2sdtv for the two post-weld treatments and as-welded specimens. Results are obtained in traction-compression R=-1. The red line corresponds to the design curve FAT 100 MPa according to IIW recommendation

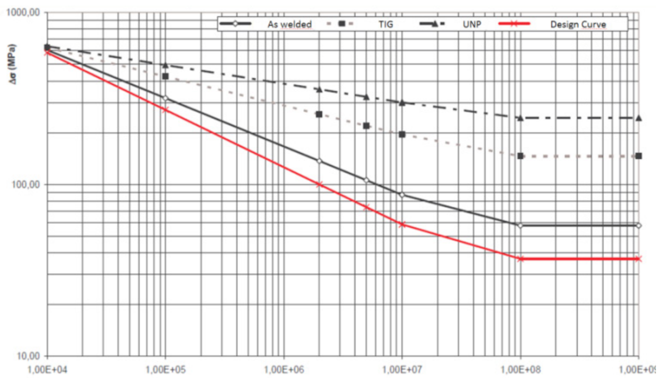

Figure 24 : Δσ-N curves for as welded, TIG dressed and UNP treated specimens

High level of improvement is observed for both methods, better results are obtained by UNP.
As presented by the authors, the calculated FAT for as welded specimen is 137 MPa, 254 MPa for TIG Dressing and 357 MPa for UNP.

5.1.4. US Navy: Systematic review of the UIT parameters on residual stresses of sensitized AA5456 and field based residual stress measurements for predicting and mitigating stress corrosion cracking[31]

This thesis focuses on the use of x-ray diffraction to measure residual stresses around welds in aluminum ship structures both in the laboratory and in the field. Tensile residual stresses are often generated during welding and, in sensitized aluminum structures, can cause extensive stress corrosion cracking. Peening techniques, such as ultrasonic impact treatment (UIT by SONATS), can mitigate and even reverse these tensile residual stresses. This research uses x-ray diffraction to measure residual stresses around welds in AA5456 before and after UIT. In particular, we examined the importance of UIT parameters such as peening amplitude and pin size. Author found that all combinations of UIT parameters removed the tensile residual stresses and resulted in compressive stress several hundred microns below the weld surface. The exact level of compressive residual stress was sensitive to the pin size used with a smaller, but measurable, dependence upon the displacement amplitude.

5.2. Studies in Progress

5.2.1. Société Nationale des Chemins de Fer - SNCF - France

As presented in the IIW Document" XIII-2545-14"[32] , SNCF is leading a study. It aims to establish the fatigue criteria for ultrasonic needle peened fillet welds under frequently observed service loads. Specimens made of fine-grained steel are tested using two stress ratios. The program will be ended by performing fatigue tests on real size components.

5.2.2. Mechanisms understanding of hammer peening effect in welded structure under fatigue loading

In collaboration with CETIM (Centre Technique des Industries Mécaniques), an expert research center, and other companies, SONATS is involved in a research program aimed to understand the UNP effect in welded structures.

If all the results, mainly from the literature survey, suggest that conventional or HFMI peening could be the optimal solution for improving the fatigue strength, for the cracked or fatigue joint repair, some questions still arise:

- What is the HFMI peening efficiency for the different domains of fatigue (low cycles, limited endurance or high cycles)?
- What are the influencing parameters (residual stress, geometry of the weld toe, hardening ...)?
- What are the involved mechanisms?

In summary, the on-going study is: "Why, how and under which conditions of solicitations, HFMI peening is effective in welded structure?".

5.2.3. FATIGUE BEHAVIOUR OF ARC WELDED ASSEMBLIES: PATHS OF IMPROVEMENT[33]

In order to take advantage of Ultra High Strength Steels (AHSS) in the automotive industry, ARCELOR MITAL would like to propose to its customers an efficient and robotized post weld treatment method. The thickness of the tested samples is 2 mm (as currently observed in automotive industry).

In a first step, several post-weld improvement methods have been tested, TIG dressing and UNP by SONATS have been selected due to the interesting fatigue life improvement observed after treatment with these techniques. Additional tests are ongoing in order to confirm previous results.

6. SONATS Experience

SONATS was founded in 1991 and has more than 20 years of experience in residual stress measurements and surface impacts treatments activated by ultrasound for fatigue life improvements. This paragraph presents some chosen examples of our experience on UNP featured projects (Please consult us if you want to know more about).

6.1. Civil engineering structures

StressVoyager® UNP offers a portable solution easy to use and has been accepted by the Port Authority of New York to extend the life of the George Washington Bridge's upper level structural steel deck (2014). Extensive UNP operations have been conducted by the contractor American Bridge during about one year (See American Bridge Journal - AB Connections, Summer 2012 on www.americanbridge.net).

Figure 25 : George Washington Bridge

Beside this remarkable example, StressVoyager® UNP has been used on bridge repairs, or new bridges, in USA, Canada, Europe and Asia. SONATS / ETI provides StressVoyager® UNP equipment leasing after dedicated training for bridge work.

6.2. Heavy machinery

Manufacturers of heavy haulage construction equipment engaged SONATS/ ETI for a solution to ensure optimum weld Quality Assurance was maintained on critical structures and weld joints, with very positive results.

Figure 26 : Example of Wheel loader part

UNP was added by our end-customers into their specifications as a method of fatigue strength and life enhancement.

6.3. Shipbuilding

Manufacturers engaged SONATS/ ETI to ultrasonically needle peen the critical welded area on several Nordic seas tankers rudders to improve fatigue strength and fatigue life.

Figure 27 : Nordic Sea Tanker Rudder repair

SONATS provided UNP service onsite to prevent cracking from fatigue and tensile stress. Treatment has been very efficient as since no more cracks have been observed.

Beside this repair project example, SONATS and its US Subsidiary Empowering Technologies, have been engaged to treat new or used ship structures (both for Steel or Aluminum).

6.4. Energy

SONATS Engineering Services team was called in by customer study department to evaluate the feasibility to impart beneficial compressive stresses on critical welded areas.

Objective was to increase the maximum load resistance on a defined design of Wind turbine to adapt to a different applicative condition. SONATS deployed Engineers and UNP operators to collaborate with Wind Energy Company and to treat weld connections on a nacelle with hard accessible work environments (see Figure 28).

Figure 28 : Wind turbine nacelle

The Wind turbine nacelle works took two weeks with two crews to complete.

6.5. Defense

SONATS developed a unique device able to needle peened very large welded area on aluminum frames of amphibious motor vehicles. It results to a high surface finish quality and improve resistance to corrosion.

Figure 29 : Aluminium frame of an amphibious military heavy equipme

6.6. Automated peening solutions

SONATS / ETI is developing a robotic device in order to apply UNP technology in an automated, controlled, repeatable process (see Figure 30).

Figure 30 : Robotic UNP on automotive chassis

7. References

[1]P. J. Haagensen and S. J. Maddox, IIW Recommendations on Post Weld Fatigue Life Improvement of Steel and Aluminium Structures XIII-2200r7-07, 2007

[2]A. V. Mordvintseva "Ultrasonic treatment of welded joints" - "Ultrasound application in welding" MMoscow, CLTI NIIE of Electrical Industry, 1959, pages 32-43.

[3]I.I. Mukhanov, Yu. M. Golubev, V.N. Philimonenko "Ultrasonic strengthening of machine steel parts" -Proceedings of the Novosibirsk Science and Technology Conference on Machine Building, ch. 1. Novosibirsk: NTO Mashprom, 1964, p. 27-39.

[4]Langenecker, Effect of Sonic and Ultrasonic Radiation of Safety Factors of Rockets and Missiles, "Journal AIAA", № 1, 1963.

[5]E. Konovalov, V. Drozdov, M. Tyavlovsky "Dynamic strength of metals", "Science and Engineering" Publishing House, Minsk 1963, 300 pages.

[6]V.I. Trufiakov, E.S. Statnikov, P.P. Mikheev and A.Z. Kuzmenko The Efficiency of Ultrasonic Impact Treatment for Improving the Fatigue Strength of Welded Joints, 1998, IIW Document XIII-1745-98

[7]P. J. Haagensen1, E.S. Statnikov2 and L. Lopez-Martinez3 - Introductory fatigue tests on welded joints in high strength steel and aluminium improved by various methods including Ultrasonic Impact Treatment (UIT), 1998 ,IIW Doc. XIII-1748-98.

[8]P.Castellucci ,V.I.Troufiakov, P.P. Mikheev ,E.CH. Statnikov – Le martelage par ultras-sons des soudures en acier HLE – Soudage et techniques connexes Mai/ Juin 1991

[9]E.CH. Statnikov, V.I. Trufiakov, P.P. Mikheev and Yu.F. Kudryavtsev. Specification for weld toe improvement by ultrasonic impact treatment. IIW Doc. XIII – 1617 - 96. (1996)

[10]E.S. Statnikov. Guide for application of UIT improving fatigue life of welded structures. IIW/IIS Doc. XIII –1757–99(1999).

[11]M.M. Pedersen, O.Ø. Mouritsen, M.R. Hansen, J.G. Andersen, J. Wenderb. Comparison of Post Weld Treatment of High Strength Steel Welded Joints in Medium Cycle Fatigue XIII-2272-09, 2009

[12]André Galtier, Efim Statnikov , The Influence of Ultrasonic Impact Treatment on Fatigue Behavior of Welded Joints in High-Strength Steel, IIW/IIS Document XIII - 1976 – 03, 2003

[14]Halid Can Yildirim & Gary B. Marquis, A round robin study of high-frequency mechanical impact (HFMI)-treated welded joints subjected to variable amplitude loading, Weld World (2013) 57:437–447

[15]Rana Tehrani Yekta, Kasra Ghahremani, Scott Walbridge, Effect of quality control parameter variations on the fatigue performance of ultrasonic impact treated welds – International journal Of fatigue - 2013

[16]Gary Marquis & Zuheir Barsoum, Fatigue strength improvement of steel structures by high-frequency mechanical impact: proposed procedures and quality assurance guidelines, Weld World DOI 10.1007/s40194-013-0077-8, 2013

[17]V.Defontaines , P. Montherat , F. Chateau , O. Brière, Fatigue Life Enhancement of Welded Structures using STRESSONIC® Ultrasonic Needle Peening - ICSP11 - Feb. 2011

[18]V.I. Trufyakov, P.P. Mikheev, Yu. F. Kudryavtsev and D.N. Reznik, Fatigue Endurance of Welded Joints, Residual Stresses and Fatigue Improvement Treatments, Paper presented at the Ship Structures Symposium '93, 1993

[19]E S Statnikov, Vladislav Korostel, Nikolay Vekshin, G Marquis, Development of Esonix ultrasonic impact treatment techniques, XIII-2098-06 ,2006

[20]Y. Kudryavtsev, J. Kleiman, A. Lugovskoy, L. Lobanov, V. Knysh, O. Voitenko, G. Prokopenko, Rehabilitation and Repair of Welded Elements and Structures by Ultrasonic Peening, IIW Document XIII-2076-05, 2005

[21]Y. Kudryavtsev, J. Kleiman, A. Lugovskoy, G. Prokopenko, Fatigue Life Improvement of Tubular Welded Joints by Ultrasonic Peening, IIW Document XIII-2117-06 2006

[22]Luis Lopez Martinez , Per J. Haagensen, LIFE EXTENSION of CLASS F and Class F2 DETAILS USING ULTRASONIC PEENING, IIW Doc. XIII-2143, 2006

[23]P. J. Haagensen and S. J. Maddox, IIW Recommendations on Post Weld Fatigue Life Improvement of Steel and Aluminium Structures, XIII-2200r7-07 (Revised 06 July 2010)

[24]Gary B. Marquis, Eeva Mikkola, Halid Can Yildirim,

[25]Zuheir Barsoum , Fatigue strength improvement of steel structures by high-frequency mechanical impact: proposed fatigue assessment guidelines, Weld World DOI 10.1007/s40194-013-0075-x, 2013

[26]American Bureau of Shipping, Commentary on the guide for the Fatigue assessment of offshore structures, April 2003 Updated in July 2014

[27]Bureau VERITAS, Rules for the Classification of Offshore Units, May 2014 edition

[28]William Wright, PE - Post-Weld treatment of a welded bridge girder by Ultrasonic impact Treatment, 1996

[29]Sougata Roy , John W. Fisher, Ben T. Yen, Fatigue resistance of welded details enhanced by ultrasonic impact treatment (UIT), International Journal of Fatigue 25 (2003) 1239–1247

[30]E.S. Statnikov, V.O. Muktepavel, V.I. Trufyakov, P.P. Mikheev, A.Z. Kuzmenko, A. Blomqvist, Efficiency Evaluation of Ultrasonic Impact Treatment (UIT) of Welded Joints in Weldox 420 Steel in accordance with the IIW Program, 2000

[31]I. Huther, H.P Lieurade, Work in progress France related to fatigue of welded components and structures, IIW Doc XIII-2436-12, 2012

[32]Marc Bousseau, Thierry Millot, Fatigue life improvement of welded structures by ultrasonic needle peening compared to TIG dressing, IIS/IIW Commission XIII DOC XIII-2125-06, 2006

[33]M. E. Haggett, Thesis : SYSTEMATIC REVIEW OF UIT PARAMETERS ON RESIDUAL STRESSES OF SENSITIZED AA5456 AND FIELD BASED RESIDUAL STRESS MEASUREMENTS FOR PREDICTING AND MITIGATING STRESS CORROSION CRACKING, NAVAL POSTGRADUATE SCHOOL March 2014

[34]I. Huther, HP. Lieurade, Work in progress in France related to fatigue of welded components and structures, IIW Doc XIII-2545-14, 2014

[35]Michel Duchet, Matthieu Amblard, Laurent Cretteur, Stéphanie Michaut, Jacques Goudemez, Bastien Weber, Olivier Brière, Vincent Desfontaine, FATIGUE BEHAVIOUR OF ARC WELDED ASSEMBLIES: PATHS OF IMPROVEMENT, Fatigue design 2011

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