Life extension, upgrade and repair of welded structures – Towards the use of High Strength Steels

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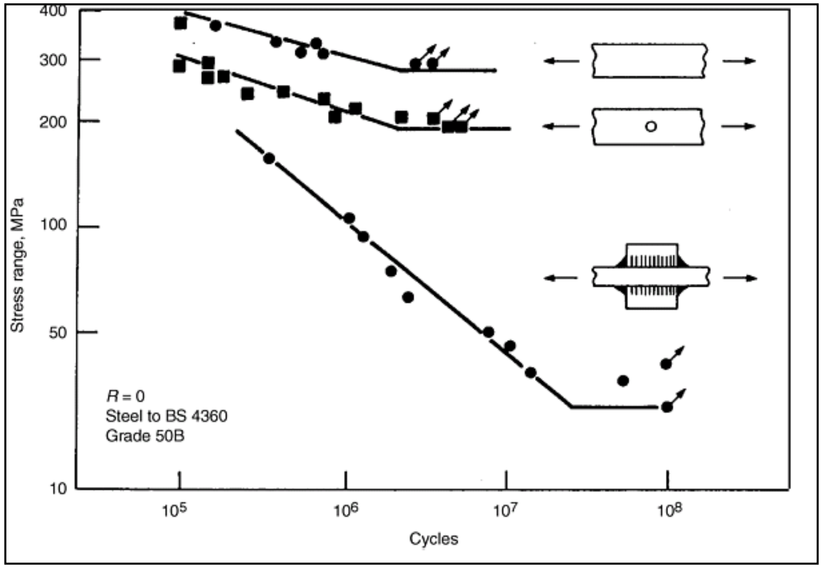
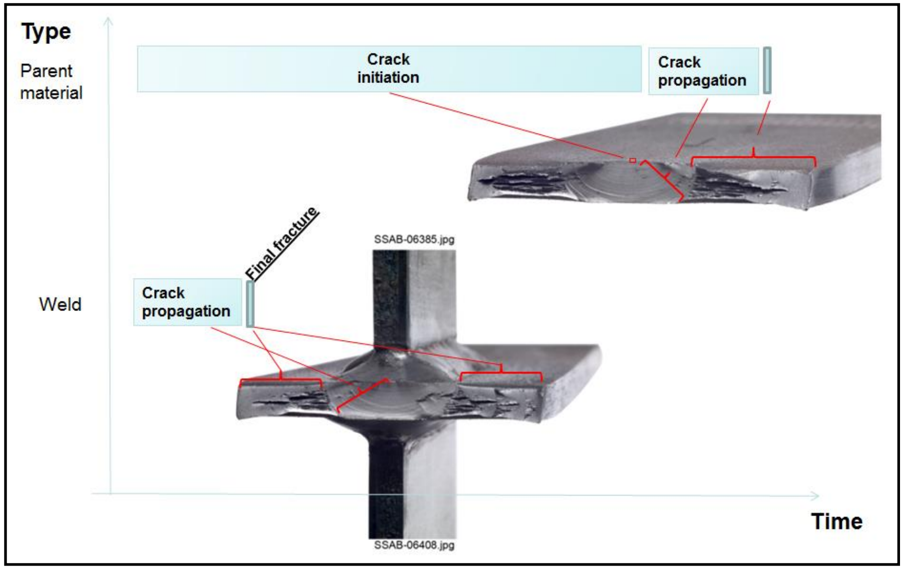
Fatigue of Welded Structures





Parent Material Compared to Welded Joints

Welds have much lower strength than the base materials due to:

- *Stress concentration due to **local** weld shape and joint geometry*
- *Weld defects and flaw which leads to early crack propagation*
- *High tensile welding stresses*

Improving the Fatigue Strength of Welded Structures

Increased Service Life

Good design practice
- Minimize fatigue loads, e.g. by avoiding resonance & vibration
- Use low SCF joints
- Avoid corrosion
- Place welds in areas with low stress

High quality fabrication
- Good choice of plate and weld materials and process
- Good weld penetration, groove geometry
- Weld quality inspection w. correlation to fatigue life

Improvement techniques
- Applied during fabrication
- Post fabrication treatment

Geometry modification techniques
- Local stress peaks are reduced
- Lower SCF
- Surface quality is improved
- Tensile welding residual stresses are reduced

Residual stress techniques
- High local compressive residual stresses are introduced
- Material work hardening
- Phase changes in weld material gives compressive stresses
- Surface quality is improved
- Lower SCF

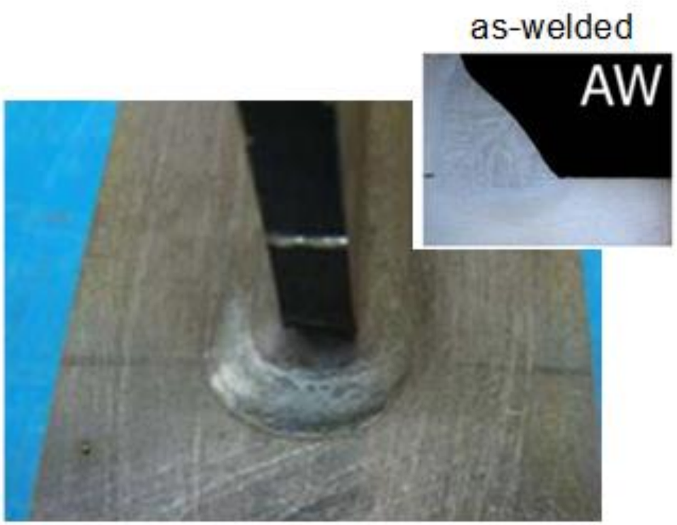
Example of HFMI devices available worldwide

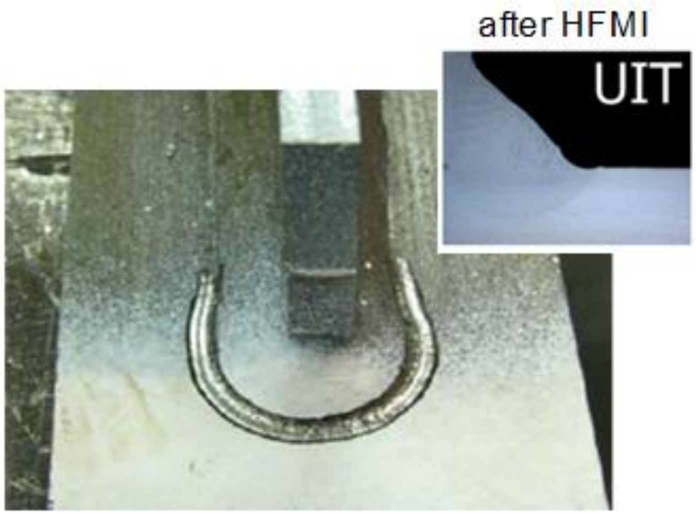
- ultrasonic impact treatment (***UIT***)
- ultrasonic peening (***UP***)
- ultrasonic peening treatment (***UPT***)
- ultrasonic needle peening (***UNP***)
- pneumatic impact treatment (***PIT***)
- high frequency impact treatment (***HiFiT***)
- Etc…
- > 90 Hz

High Frequency Mechanical Impact - HFMI

Example of HFMI indenter sizes and configurations

Typical weld toe profile in the as-welded condition and following HFMI treatment

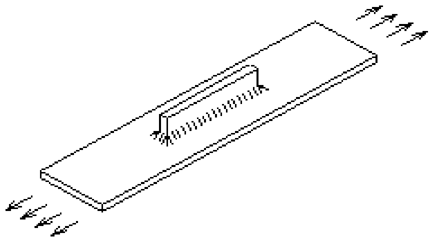


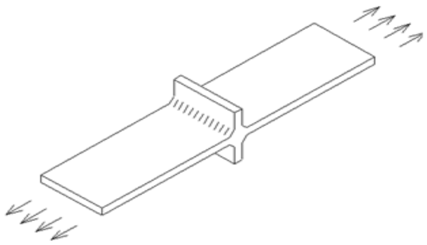


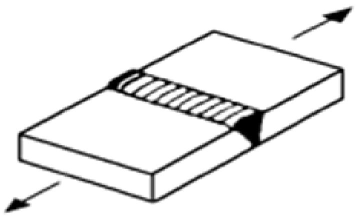
What Does the Current IIW Guidelines Say?

Nominal stress : Existing IIW FAT classes

f_y (MPa)	longitudinal welds	transverse welds	butt welds
	[1]as-welded, m = 3		
all f_y	71	80	90
	[2]improved by hammer or needle peening, m = 3		
$f_y \leq 355$	90	100	112
$355 < f_y$	100	112	125





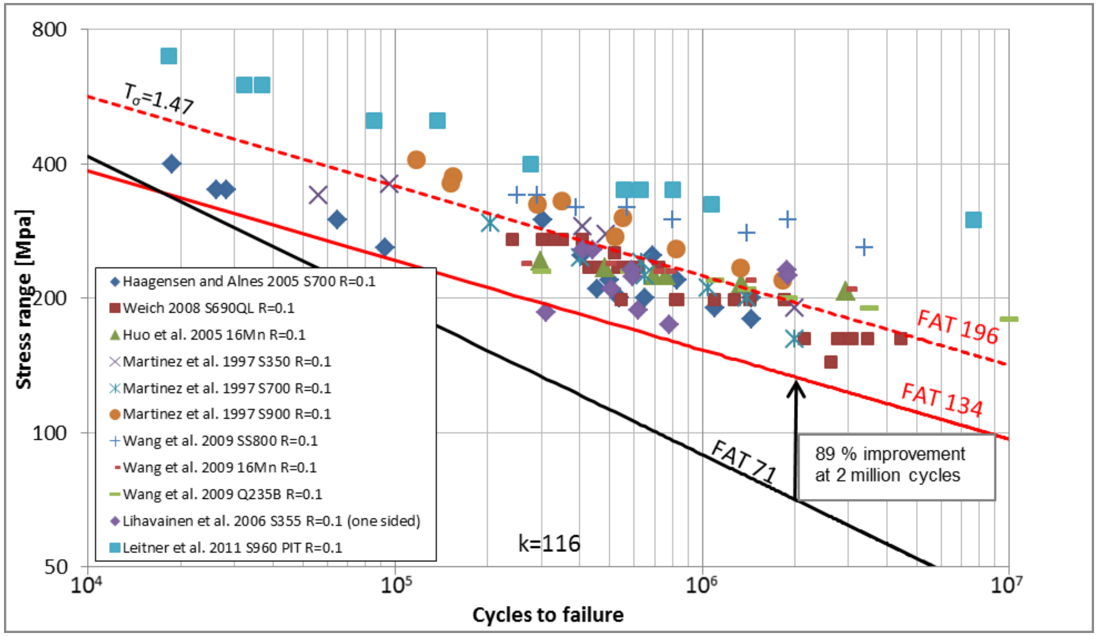


1) Hobbacher, A.: IIW Recommendations for Fatigue Design of Welded Joints and Components., WRC Bulletin 520, The Welding Research Council, New York. (2009)
2) Haagensen, P. J., Maddox, S. J.: IIW Recommendations on methods for improving the fatigue lives of welded joints, Woodhead Publishing Ltd., Cambridge. International Institute of Welding, Paris. (2013)
3) Fricke, W.: IIW Recommendations for the Fatigue Assessment of Welded Structures by Notch Stress Analysis, Woodhead Publishing Ltd., Cambridge. (2012)

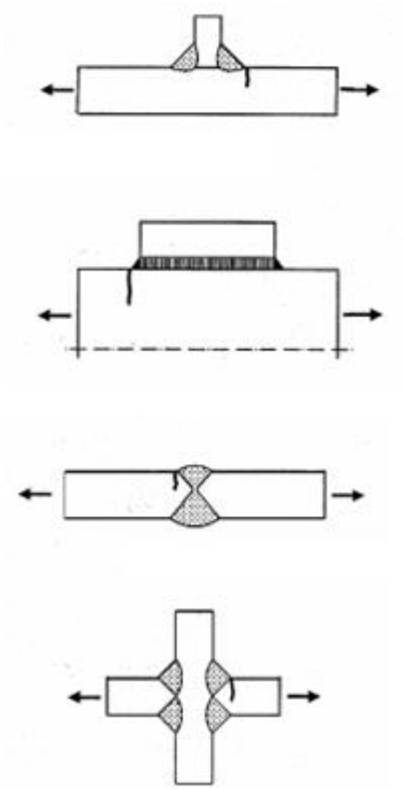
Proposed Fatigue Strength Improvement using HFMI

Some of Assumptions:

- The improvement method covered in these studies is applied to the ***weld toe***
- All of fatigue design methods for HFMI improved welds are based on an assumed S-N slope of ***m = 5*** and fatigue strength improvement factors are defined at ***N = 2·10^{6} cycles***

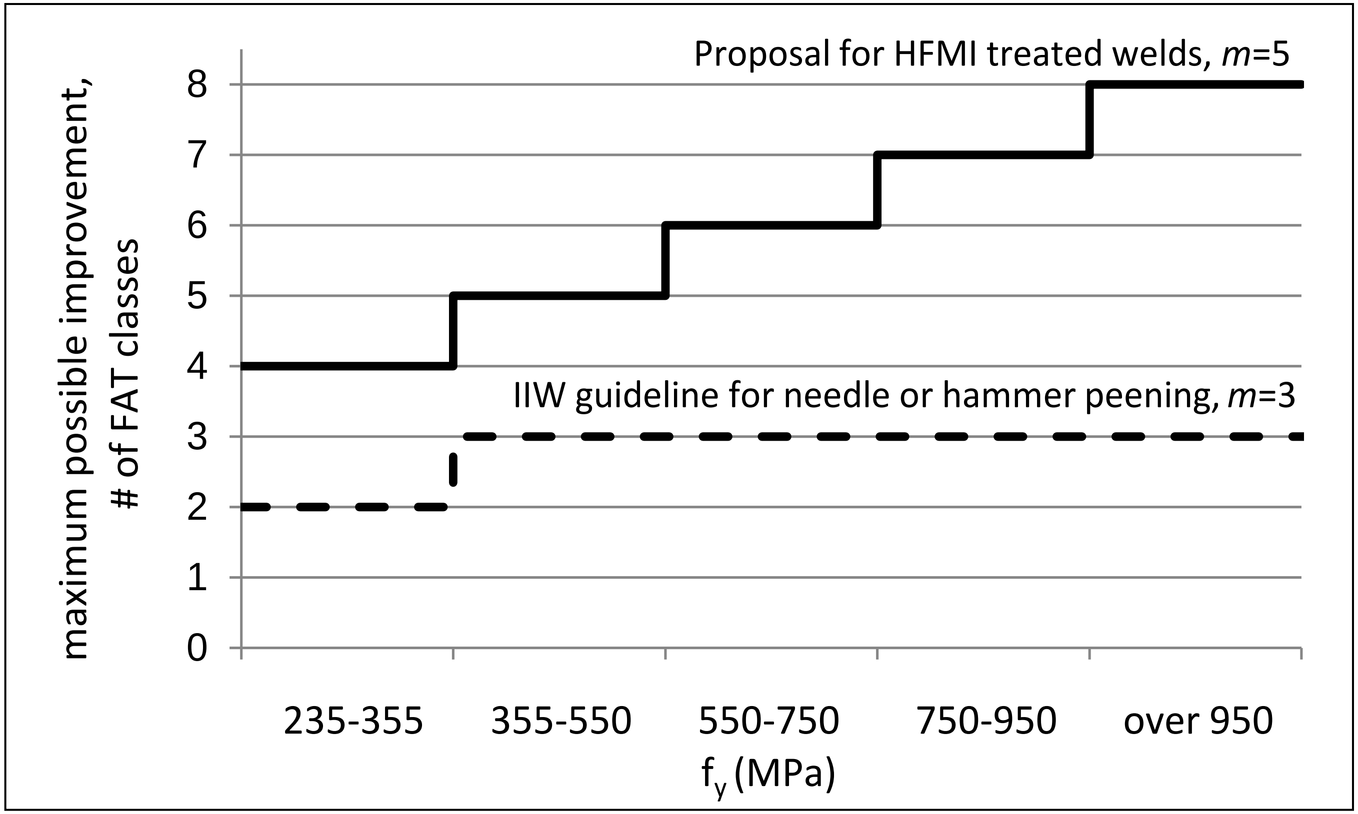


Examples of joints suitable for improvement



Proposed Fatigue Strength Improvement using HFMI

a design recommendation including one fatigue class increase in strength (about 12.5%) for every 200 MPa increase in static yield strength was proposed and shown to be conservative with respect to all available data.



Proposed Fatigue Strength Improvement using HFMI

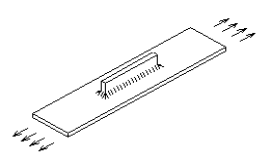
Nominal Stress

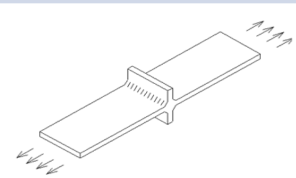
Existing IIW FAT classes for as-welded and hammer or needle peened welded joints and the proposed FAT classes for HFMI treated joints as a function of f_y

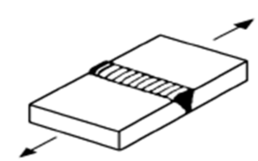
f_y (MPa)	longitudinal welds	cruciform welds	butt welds
	as-welded, m = 3		
all f_y	71	80	90
	improved by hammer or needle peening, m = 3		
$f_y \leq 355$	90	100	112
$355 < f_y$	100	112	125
	improved by HFMI, m = 5		
$235 < f_y \leq 355$	112	125*	140*
$355 < f_y \leq 550$	125	140	160
$550 < f_y \leq 750$	140	160	180
$750 < f_y \leq 950$	160	180*	-
$950 < f_y$	180	-	-

From this study (HFMI rows)

* no data available







Proposed Fatigue Strength Improvement using HFMI

Loading effects

- the guideline states that the techniques are not suitable for R > 0.5 or when $S_{max} > 0.8 f_y$

- **Stress ratio:**

$k_R = 1.075 - 0.75 \cdot R$ for $0.1 \leq R \leq 0.5$

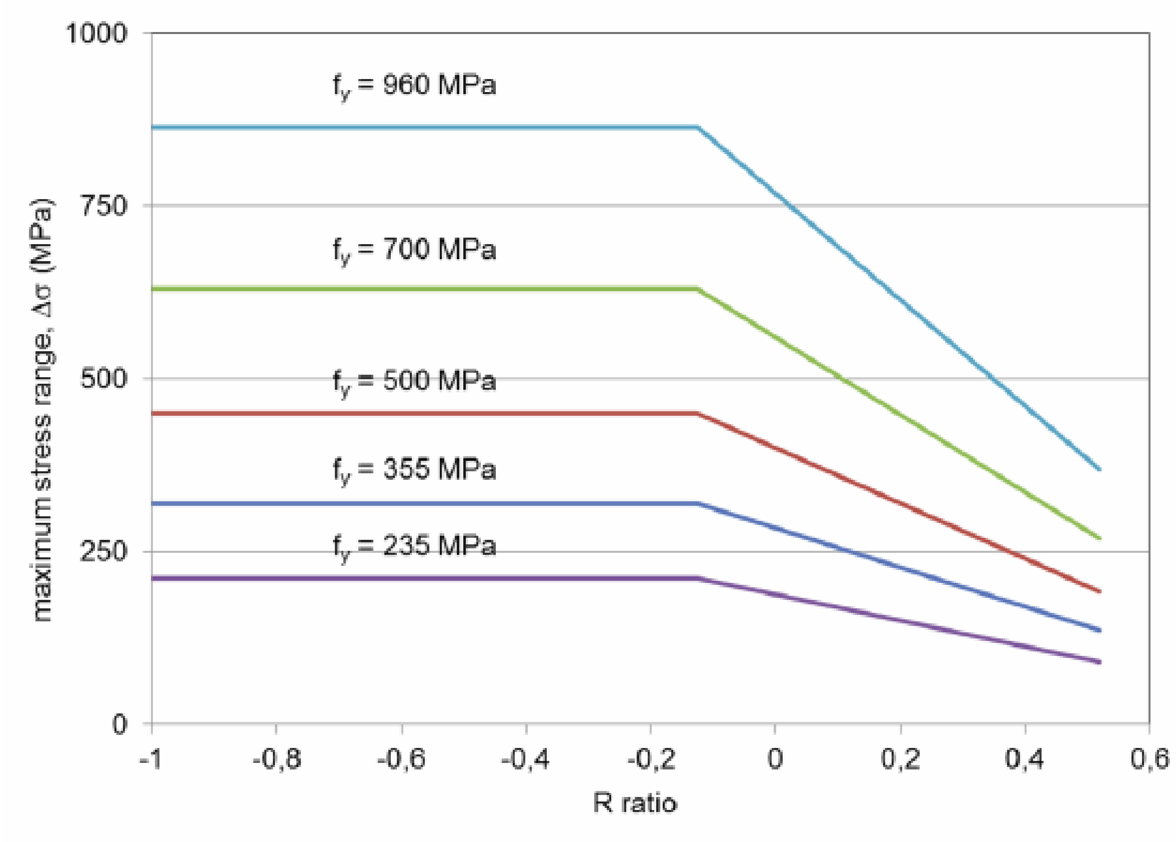
$k_R = 1.0$ for $R < 0.1$

- Minimum reduction in the number of FAT classes in fatigue strength improvement for HFMI treated welded joints as presented in previous Figure based on R ratio.

R ratio	Minimum FAT class reduction
R ≤ 0.15	No reduction due to stress ratio.
0.15 < R ≤ 0.28	One FAT class reduction
0.28 < R ≤ 0.4	Two FAT classes reduction
0.4 < R ≤ 0.52	Three FAT classes reduction
0.52 < R	No data available. The degree of improvement must be confirmed by testing

Loading effects and variable amplitude loading

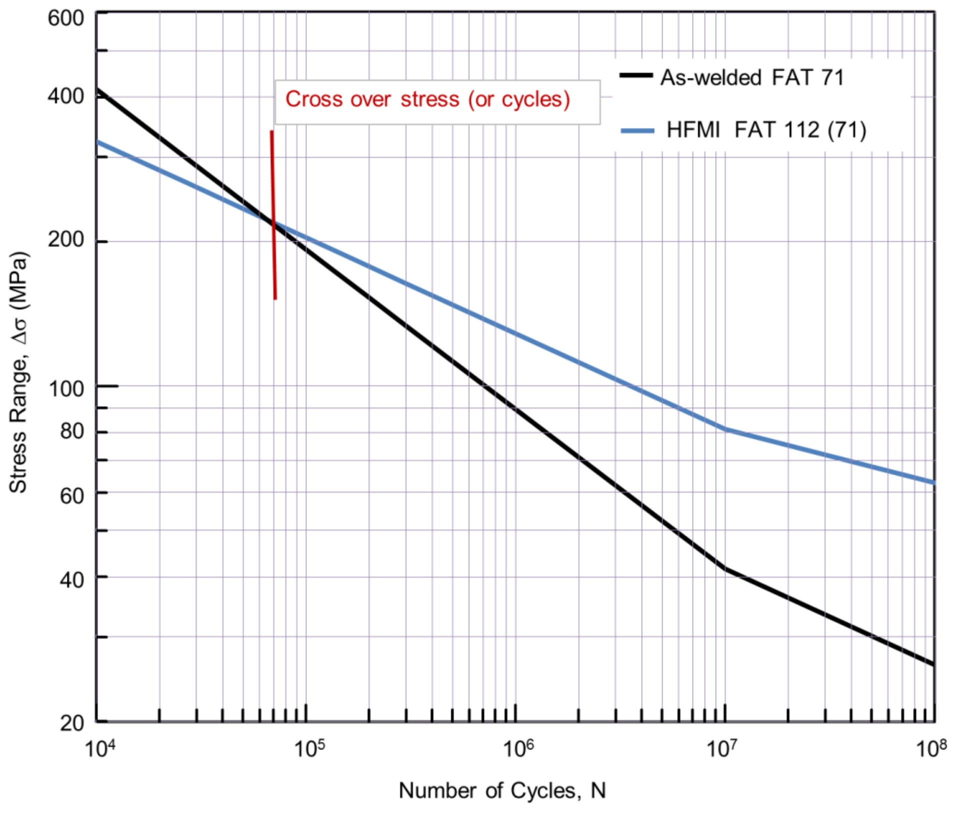
- the guideline states that the techniques are not suitable for R > 0.5 or when $S_{max} > 0.8\ f_y$
- Limitation on maximum constant amplitude stress range, Δσ, that can be applied to a weld in order to claim benefit from HFMI treatment (in MPa)



The influence of steel strength :

- Computed cycle limit below which HFMI is not expected to result in fatigue strength improvement as a function of steel strength.

f_y (MPa)	N (cycles)
< 355	72 000
355 – 550	30 000
550 – 750	12 500
> 750	< 10 000



Proposed Procedures and Quality Assurance Guidelines for HFMI

Procedures

Operator Training:

- 1-2 days of operator training
- identification of fatigue critical regions is also important to avoid extra costs and treatment

Weld Preparation:

- weld profile quality level B in ISO 5817 : Undercuts, Excessive overfill, Excessive concavity and Overlaps.
- proper weld profile

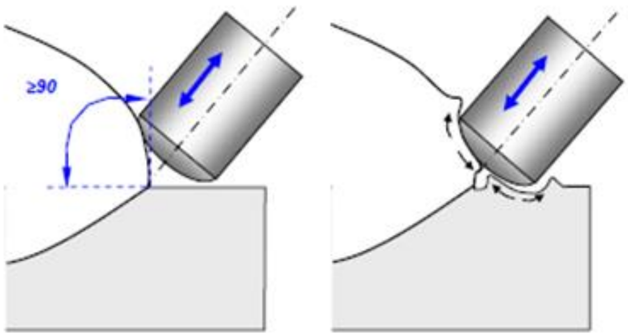
Safety Aspects:

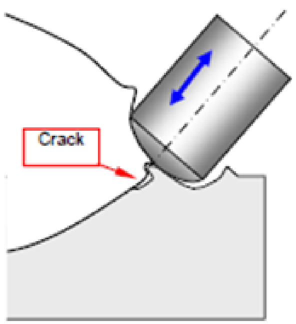
- less noise and vibration
- eight hour work shift

Proposed Procedures and Quality Assurance Guidelines for HFMI

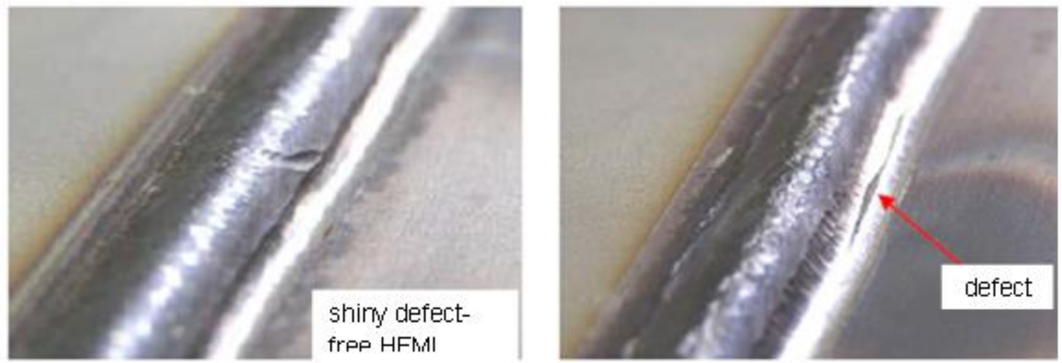
Quality control (Qualitative Measures):

Potential introduction of crack-like defect due to HFMI treatment of a weld with a steep angle or with too large of an indenter

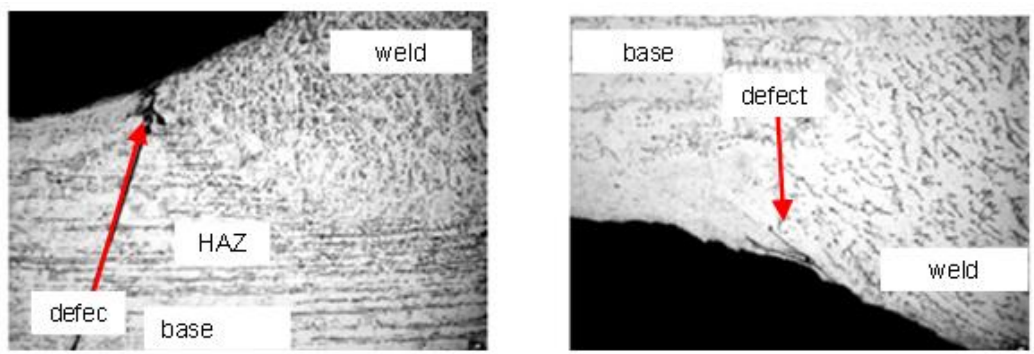




Resulting groove for a properly treated (left) and improperly treated weld toe (right)



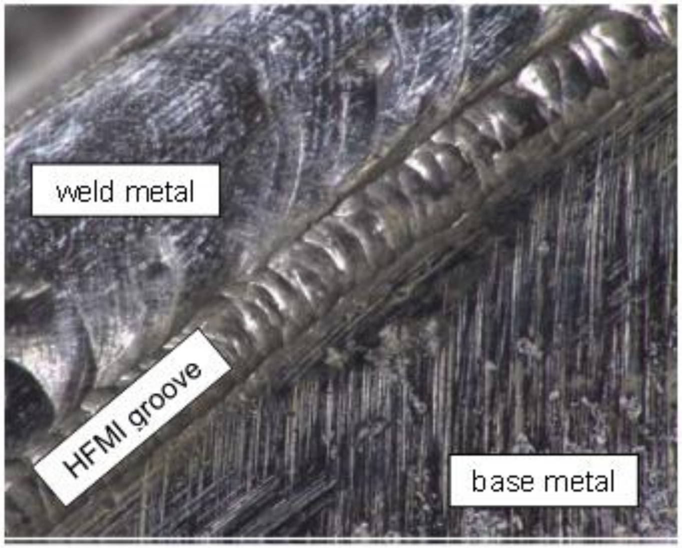
Micrographs of the induced crack-like defects due to improper HFMI treatment



Quality control (Qualitative Measures):

- No thin line representing original fusion line should be visible the groove , No individual strikes visible

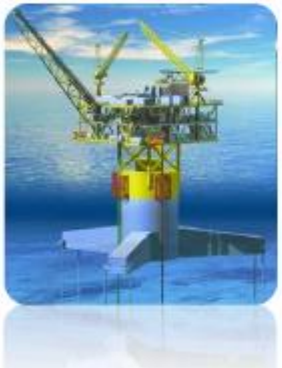
thin crack-like defect which reduces or eliminates the effectiveness of the HFMI treatment



defect-free groove but with individual indenter strike still visible indicating the need for additional passes

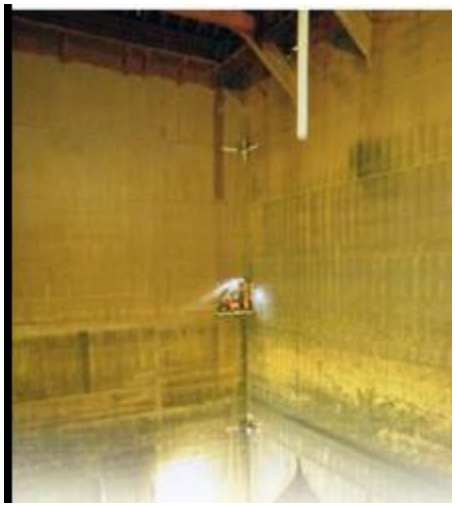
Industrial Applications

bhpbilliton **TLP Neptune**



Fatigue hot-spots found in brackets supporting the TLP pontoons: **HFMI** successfully applied

bp **FPSO Schiehallion**



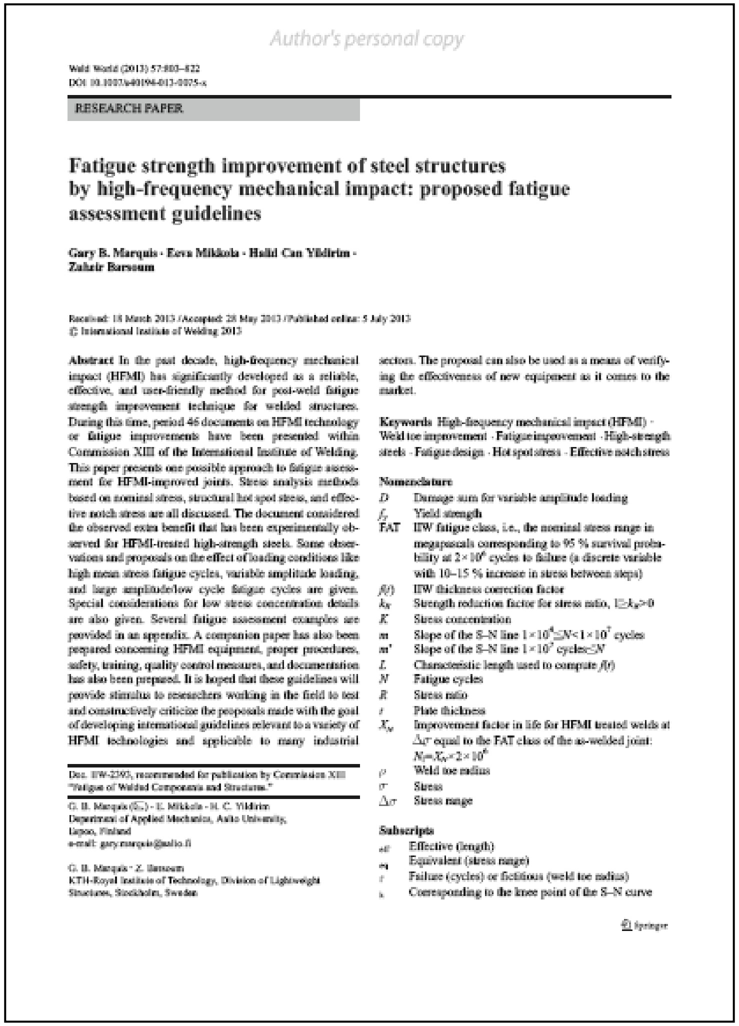
Fatigue hot-spots found in six FPSO cargotanks, Bulkhead and bracket welds treated by **HFMI** rope access team

Conclusions

- The design proposal is considered to apply to ***plate thickness 5 to 50 mm*** and for ***235 MPa ≤ f_y ≤ 960 MPa***.
- Fatigue resistance curves for HFMI improved welds are based on an assumed S-N slope of **m = 5** in the region ***$1{\cdot}10^4 \le N < 1{\cdot}10^7$*** cycles and, for variable amplitude loading, **m' = 9 for $1{\cdot}10^7 \le N$**.
- Stress assessment may be based on ***nominal stress, structural hot spot stress or effective notch stress*** using stress analysis procedures as defined by the IIW.
- The design proposal includes proposals for the 1) effect of material strength, 2) special requirements for low stress concentration weld details, 3) high R-ratio loading conditions and 4) variable amplitude loading.
- A companion document concerning relevant equipment, proper procedures, material requirements, safety, training requirements for operators and inspectors, quality control measures and documentation has also been prepared and is published in this same issue.
- Succesful validation have been shown on larger industrial welded structures

Recent Publications

HFMI Guidelines Publications *(Welding in the World, 2013 and 2014)*



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RESEARCH PAPER

Fatigue strength improvement of steel structures by high-frequency mechanical impact: proposed fatigue assessment guidelines

Gary B. Marquis · Eeva Mikkola · Halid Can Yildirim · Zuheir Barsoum

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Abstract In the past decade, high-frequency mechanical impact (HFMI) has significantly developed as a reliable, effective, and user-friendly method for post-weld fatigue strength improvement technique for welded structures. During this time, period 46 documents on HFMI technology or fatigue improvements have been presented within Commission XIII of the International Institute of Welding. This paper presents one possible approach to fatigue assessment for HFMI-improved joints. Stress analysis methods based on nominal stress, structural hot spot stress, and effective notch stress are all discussed. The document considered the observed extra benefit that has been experimentally observed for HFMI-treated high-strength steels. Some observations and proposals on the effect of loading conditions like high mean stress fatigue cycles, variable amplitude loading, and large amplitude/low cycle fatigue cycles are given. Special considerations for low stress concentration details are also given. Several fatigue assessment examples are provided in an appendix. A companion paper has also been prepared concerning HFMI equipment, proper procedures, safety, training, quality control measures, and documentation has also been prepared. It is hoped that these guidelines will provide stimulus to researchers working in the field to test and constructively criticize the proposals made with the goal of developing international guidelines relevant to a variety of HFMI technologies and applicable to many industrial sectors. The proposal can also be used as a means of verifying the effectiveness of new equipment as it comes to the market.

Keywords High-frequency mechanical impact (HFMI) · Weld toe improvement · Fatigue improvement · High-strength steels · Fatigue design · Hot spot stress · Effective notch stress

Nomenclature

D	Damage sum for variable amplitude loading
f_y	Yield strength
FAT	IIW fatigue class, i.e., the nominal stress range in megapascals corresponding to 95 % survival probability at 2×10^6 cycles to failure (a discrete variable with 10–15 % increase in stress between steps)
$f(t)$	IIW thickness correction factor
k_R	Strength reduction factor for stress ratio, $1\geq k_R>0$
K	Stress concentration
m	Slope of the S–N line $1\times10^4\leq N<1\times10^7$ cycles
m'	Slope of the S–N line 1×10^7 cycles$\leq N$
L	Characteristic length used to compute $f(t)$
N	Fatigue cycles
R	Stress ratio
t	Plate thickness
X_N	Improvement factor in life for HFMI treated welds at $\Delta\sigma$ equal to the FAT class of the as-welded joint: $N_f=X_N\times2\times10^6$
ρ	Weld toe radius
σ	Stress
$\Delta\sigma$	Stress range

Subscripts

eff	Effective (length)
eq	Equivalent (stress range)
f	Failure (cycles) or fictitious (weld toe radius)
k	Corresponding to the knee point of the S–N curve

Doc. IIW-2393, recommended for publication by Commission XIII "Fatigue of Welded Components and Structures."

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RESEARCH PAPER

Fatigue strength improvement of steel structures by high-frequency mechanical impact: proposed procedures and quality assurance guidelines

Gary Marquis · Zuheir Barsoum

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Abstract High-frequency mechanical impact (HFMI) has emerged as a reliable, effective, and user-friendly method for post-weld fatigue strength improvement technique for welded structures. During the past decade, 46 documents on HFMI technology for fatigue improvements have been presented within Commission XIII of the International Institute of Welding (IIW). This paper presents an overview of the lessons learned concerning appropriate HFMI procedures and quality assurance measures. Due to differences in HFMI tools and the wide variety of potential applications, certain details of proper treatment procedures and quantitative quality control measures are presented generally. Specific details should be documented in an HFMI procedure specification for each structure being treated. It is hoped that this guideline will provide a stimulus to researchers working in the field to test and constructively criticize the proposals made with the goal of developing international guidelines relevant to a variety of HFMI technologies and applicable to many industrial sectors. A companion document presents a fatigue design proposal for HFMI treatment of welded steel structures. The proposal is considered to apply to steel structures of plate thicknesses of 5 to 50 mm and for yield strengths ranging from 235 to 960 MPa. Stress assessment may be based on nominal stress, structural hot spot stress, or effective notch stress.

Keywords High-frequency mechanical impact (HFMI) · Weld toe improvement · Fatigue improvement · Quality control

1 Introduction

In 2007, Commission XIII: Fatigue of Welded Components and Structures approved the best practice recommendations concerning post-weld treatment methods for steel and aluminum structures [1]. This recommendation covers four commonly applied post-weld treatment methods: burr grinding, tungsten inert gas (TIG) remelting (i.e., TIG dressing), hammer peening, and needle peening. Burr grinding and TIG remelting are generally classified as geometry improvement techniques for which the primary aim is to eliminate weld toe flaws and to reduce local stress concentration by achieving a smooth transition between the plate and the weld face. Hammer peening and needle peening are classified as residual stress modification techniques which eliminate the high tensile residual stress in the weld toe region and induce compressive residual stresses at the weld toe. These methods also result in a reduced stress concentration at the weld toe. The guidelines also give practical information on how to implement the four improvement technologies, namely good work practices, training, safety, and quality assurance.

The improvement techniques described in these recommendations are intended to be used both for increasing the fatigue strength of new structures and for the repair or upgrade of existing structures. It has consistently been emphasized that, especially with respect to new structures, weld improvement techniques should never be implemented to compensate for poor design or bad fabrication practices. Instead, improvement measures should be implemented as a means of providing additional strength after other measures have been taken.

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Thank You for Your Kind Attention!

Questions?