Steel Structures
- Fatigue Life Enhancement by High Frequency Peening

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Motivation

Increased demands for steel structures

• Extended service life for new and existing structures
• Reduction of the construction weight for cost reduction
• Increasing / new loads

New challenges for the fatigue strength of steel structures
Increased service life of new and existing constructions

example: Deutsche Bahn

- Total bridge constructions with an overall installed size of 52 Mrd. €
- 25% are steel and iron bridges (13 Mrd. €)
- 60% of these are welded steel structures
- 70% of all steel and iron bridges are at the end of their service life

- Enormous investment needs of up to 9 Mrd. €
Increased service lives of new and existing constructions
Increased service lives of new and existing constructions

Road way expansion joints
Optimized structures

Reduction of the construction weight for cost reduction
Optimized structures

Reduction of the construction weight for cost reduction
Increasing / new loads

Larger portainer cantilevers
New loads

Windloading - onshore wind energy sector
New loads

Wind- und waveloading - offshore wind energy sector
Fatigue design for structural details

- Structural and material caused notches define the service life
- Weld toes are notches with high notch stresses

Increase of the local fatigue strength and reduction of the notch stresses may increase the overall service life of the construction

Application of weld improvement methods
**Improvement methods**

- Grinding
- MIG-improvement
- Hammer peening
  - Needle peening
- High frequency hammer peening
- Shot peening

**Deformation of the weld toe**

- Reduction of notch stresses

**Mechanical edge layer improvement**

- Surface hardening
- Compressive residual stresses
High frequency hammer peening

- Hammer frequency: ≥ 200 Hz
- Pin diameter: 3 to 5 mm

- Present investigations prove the fatigue life increasing effects
- Systematic investigations regarding the beneficial effect are conducted
High frequency hammer peening
Plastic deformation of the weld toe

- Uniform deformation of the weld toe
- Removal of cold laps

Mean weld toe radii of 1.5 – 2 mm
Depth of the indents 0.05 – 0.4 mm
Surface hardening of a mild steel S355J2

Obvious surface hardening by up to 180HV0.3 to 400HV0.3
Influence depth of 0.3 – 0.4 mm
Numeric Simulation of the development of residual stresses on a plate (Ansys 10.0)

Stresses perpendicular to the projection plane, transverse to the treatment direction
Production of residual stresses

Surface residual stresses

Transverse residual stresses [MPa] vs. Distance from the middle of the weld [mm]

Graph showing the production of residual stresses with lines for as welded, UIT, and HiFIT treatments. The graph indicates a comparison of transverse residual stresses at various distances from the middle of the weld.
Residual stresses after a treatment in depth direction

Transverse residual stresses

- Effect up to a depth of 1.5 – 2.0 mm
- Compensating tensile residual stresses in deeper material layers
- Smaller maximum values of the tensile stresses, due to a wider area
Increase of the fatigue strength compared to the FAT-class of Eurocode by 100%

For mild steel reduced efficiency at high stress levels compared to lower stress levels (flatter SN-curves)
Blasting of the surface after HiFIT / UIT

- Additional hardening
- Increased fatigue strength but wider scatter
- Fatigue life extension due to hardening
Influence of fatigue pre-damage before the treatment

Fatigue pre-damaged and following HiFIT/UIT-treated butt welds

Same increase of the fatigue life as for a treatment of specimens without pre-damage
Existing design codes

Eurocode
- No consideration of improvement methods
  Exception: grinding

IIW-Recommendations: IIW-XIII-2200-07 (Intern. Inst. of Welding)
- Improvement methods are covered

common hammer peening
- Improvement factors for FAT-classes with remaining slope
  - 30% of $R_e < 350$ MPa
  - 50% of $R_e > 350$ MPa
- Maximum nominal compressive stresses < 25% of the yield strength
- Stress ratio $R < 0$ : design based on stress ranges
- Stress ratio of $R \geq 0$ design based on maximum stress

Application of high frequent hammer peening in civil engineering
- “Zustimmung im Einzelfall” – acceptance for particular cases
Developed design concept

Increase of the fatigue strength

\[ \Delta \sigma_{c,\text{HP}} = K_{\text{HP}} \cdot \Delta \sigma_c \]

with \( K_{\text{HP}} = k_0 \cdot k_{\text{Re}} \cdot k_R \)

- \( k_0 \): improvement factor
- \( k_{\text{Re}} \): material factor respecting the yield strength \( R_e \)
- \( k_R \): loading factor respecting the stress ratio \( R \)

\[ k_0 = 1.6 \]
\[ k_{\text{Re}} = 1 + 0.6 \cdot (1 - 355 / R_e) \]

\[ k_R = \begin{cases} 1.075 - 0.75 \cdot R & 0.1 \leq R \leq 0.5 \\ 1.0 & R < 0.1 \end{cases} \]

Slope of the SN-curve

\[ m = 5 \]
Calculated fatigue strength - butt weld

![Graph showing calculated fatigue strength for butt welds with detailed data points and lines representing different models and materials like HiFIT/UIT S355J2 and HiFIT/UIT 5690QL.](image)
Quality control

Aim
- Constant quality of the improvement
- Optimized deformation of the weld toe
- High compressive residual stresses in the treated zone

Treatment shows little scatter in case of applying optimized treatment parameters:
- Pin shape:
  - diameter: \( d = 3 \) mm
  - pin tip: radius \( R = 1.5 - 2 \) mm
- Depth of the indent
  - Less than 0.25 mm
- Application angle \( \alpha \)
  - 60° to 80°

Visual inspection in situ
Application to transition pieces of wind energy plants
Application to transition pieces of wind energy plants
Application to a road bridge: Schenkendorfstr. München
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Economic structures

example: factory / storage crane
Crane capacity: 90 t
span: 26 m
Carrying class: H3B6
Decisive notch details:
stiffeners of flanges and webs:

Existing status- ground:
after HiFIT/UIT:

- notch class K2 (DIN 15018)
- notch class K0 to K1 (DIN 15018)

→ reduction of the steel weight by 18%
(= 10 to)
Conclusions

High frequency hammer peening (HiFIT and UIT) are very efficient means to increase the fatigue life of welds

Compared to as welded details

- Up to 100 % higher fatigue strength
- 5- to 15-times of the fatigue life
- Same efficiency for pre-damaged notch details (precondition: crack depths less than 0.5 mm)

Effective application of high strength steel

- Further increased fatigue strength
- Fatigue strength no more limiting value
- Higher compressive residual stresses compared to mild steel
- Extended life time especially for high stresses
Conclusion

Practical application

Design
- Life time estimation for details respecting improvement factors for notch classes

Quality control
- Application of defined treatment parameters
- Control of treatment parameters
- Visual inspection
Thank you for your kind attention!