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EXPERIMENTAL CHARACTERISATION OF FATIGUE RESISTANCE
OF PIPE-TO-PLATE WELDED JOINTS UNDER TORSION LOADING

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PREMISE

Welding is a widely employed technique for joining members to form complex components/structures; it is well adaptable to automation. There are many factors influencing the fatigue strength such as process parameters, local welding geometry, defects (porosity, inclusions, non perfect metal melting, small cracks ...), residual stresses, materials properties etc.

**Analysis procedures** classified on the basis of the parameters taken as reference:

- **nominal stress methods** (usually considered in standards),
- **structural stress methods**, “hot spot” stresses
- **local stress methods**, in which the stress at the weld toe/root is considered, by assuming a fictitious radius (Neuber, Radaj), or by a field parameter such as the N-SIF (Lazzarin et al.)
- **average value of a stress component** or **strain energy**, locally evaluated in the surrounding of the most stressed region (Tovo, Livieri)
OBJECT OF THE PRESENT RESEARCH

Experimental characterisation of the fatigue strength of welded joints that are used in railway bogies (the analysis will be extended to other joint geometries)

*pipe-to-plate welded joint*

![Diagram of a pipe-to-plate welded joint](image)
TEST SPECIMENS AND LOAD CONDITION

Load conditions

**Torsion** \((R=-1, 0)\)

**Bending** \((R=-1, 0)\)

**Combined torsion and bending** \((R=-1, 0)\)
Design requirements:
• strength
• small differences in pipe diameters (<0.5mm) have to be allowed
• avoid “spurius” bending loads (e.g. due to component weight)
TEST RIG

Design torque $M_t = 45$ kNm
TEST RIG
Small difference in outside diameter

6 M12 bolts
39NiCrMo3
4 M20 bolts

Keyseats
key
EXPERIMENTAL TEST SETUP

Analysis of possible errors and related undesired stresses (without any monitoring during the setup phase)

\[
\begin{align*}
\Delta \theta &= (\delta_{1P}) + F (\delta_{11}) + M (\delta_{12}) \\
\Delta \theta &= (\delta_{11}) (F) + (\delta_{21}) (M) = C (F)
\end{align*}
\]

Strain gauges measurements on two orthogonal planes
EVALUATION OF SET UP ERRORS AND CONSEQUENT STRESSES INDUCED IN THE SEAM WELD

\[
\begin{pmatrix}
\Delta \\
\theta
\end{pmatrix} =
\begin{pmatrix}
\delta_{11} & \delta_{12} \\
\delta_{21} & \delta_{22}
\end{pmatrix}
\begin{pmatrix}
F \\
M
\end{pmatrix} = c
\begin{pmatrix}
F \\
M
\end{pmatrix} = c^{-1}
\begin{pmatrix}
\Delta \\
\theta
\end{pmatrix}
\]

Bending moment acting on the cross section where the strain gages are located: \( M_e(\Delta, \theta) = F \cdot L_e + M \)

\[
\varepsilon_i = \frac{M_{el} D}{EJ} \frac{D}{2} = \frac{M + F L_{el}}{EJ} \frac{D}{2} = \frac{D}{2EJ} \left[ c^{-1} \begin{pmatrix}
\Delta \\
\theta
\end{pmatrix} \right]^T \begin{pmatrix}
L_{el} \\
1
\end{pmatrix}
\]

Starting from the strain measures the following quantities can be obtained:
- displacement and rotation of the specimen end section
- stresses acting on the seam weld (after having obtained the constraint reactions exerted by the clamp)

Typical errors of about 0.3mm e 0.1°, which correspond to bending stress of the order of 50 MPa in the seam weld (not acceptable for tests)
Through the thickness defect detection (test arrest criterium)

Small pressurized volume

Pressurized air and connection to pressure transducer

Strain gauges used during test setup
It was obtained that very low "spurious" stresses (below 10 MPa) can be achieved by monitoring the strains on two orthogonal plane, mounted nearby the seam weld.
TEST RIG
SET UP FOR TESTS UNDER PURE BENDING AND COMBINED BENDING AND TORSION
EXPERIMENTAL RESULTS
Alternate torque vs $N_R$
EXPERIMENTAL RESULTS
Alternate shear stress vs $N_R$

Nominal shear stress

$$\tau = \frac{M D_{ext}}{J_0 \frac{a}{2}}$$
EXPERIMENTAL RESULTS

Low $R$ effect (negligible)

$$
\tau_a = 159 N_R^{-0.074}
$$

$k = 13.5$
ANALYSIS OF FINAL RUPTURE SURFACES
Defect nucleation mainly at the weld root
ANALYSIS OF FINAL RUPTURE SURFACES
ANALYSIS OF FINAL RUPTURE SURFACES
Relatively high radius at the weld toe (3mm)
EXAMPLE OF VERY GOOD WELDING!
FE ANALYSIS OF THE WELDED JOINT BY THE FICTITIOUS RADIUS (1 mm) APPROACH (plane model with Fourier elements)
PURE TORSION

3 mm radius
A TEST CAMPAIGN ON DIFFERENT SPECIMEN GEOMETRIES IS GOING TO START

(Joint used in motorcycle frame manufacturing)
CONCLUSIONS AND FUTURE ACTIVITIES

- Activity aimed at characterising the fatigue strength of a typical welded joint with respect to different loading conditions.

- Development of a purposely developed test rig, including the defect detection system.

- Torsion: the experimental results showed a negligible effect of the load ratio $R$ and a lower slope of the S-N curve, if compared to reference value given in standards. This was attributed to the arrest criteria (detection of a small crack).

- For torsion loading, defect nucleation took place at the weld root.

- The experimental campaign is ongoing in order to extend the results database and increase the level of accuracy.

- Tests are being started also for different specimen geometries.

- Experimental results will be analysed by FE analyses.
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