PO.ID 086

Fitting new S-N curves for welded tubular joints

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Abstract

It is an essential requirement to make the offshore renewable energy industry more economically efficient in order to greater investment. Extending the service life of the offshore wind turbine support structures would contribute to the reduction of the costs. The S-N curve approach is used in the fatigue-life assessment, in particular the T' curve is applied for the fatigue behaviour of welded tubular joints. This curve does not make differentiation between joint types or applied loads, which affects the fatigue strength leading to obtain a value which may not be the optimum. Therefore, this research intends to prove that much work must be carried out on the development of new S-N curves to reduce safety factors avoiding unnecessary costs of over-conservatism. For this purpose, different regression analyses were performed considering different: sample sizes, independent variables, variable transformations, and stress levels.

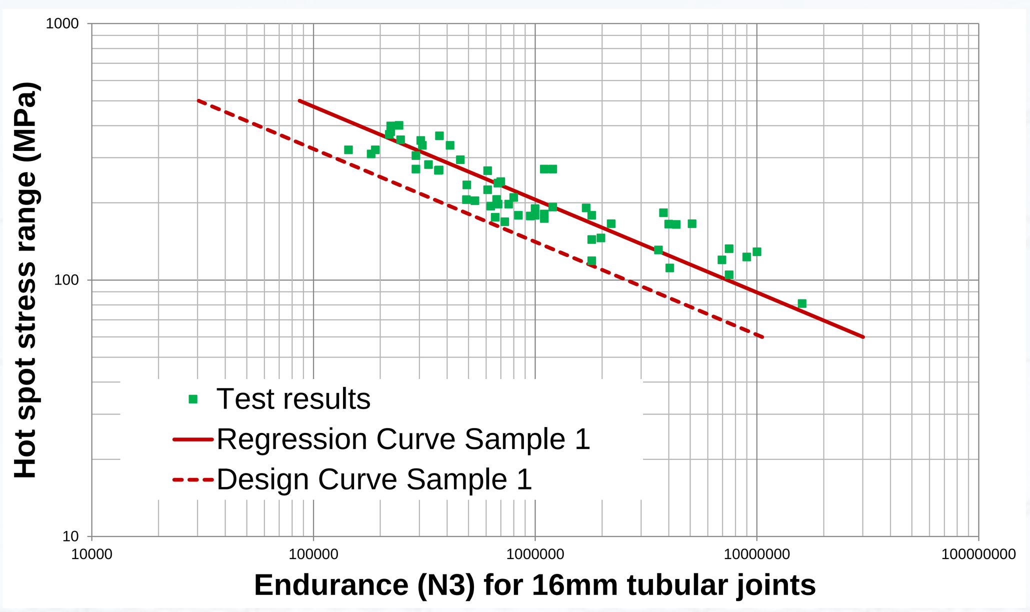
Linear Regression Analyses

92 test results from the United Kingdom Offshore Steels Research Project (UKOSRP) and the European Coal and Steel Community (ECSC) sponsored research programme [1].

- ✓ Normality (Skewness , Kurtosis & Shapiro-Wilk test)
- ✓ Homoscedasticity (Bartlett's test)
- ✓ Linearity (Pearson's coefficient)
- ✓ No multicollinearity (Variance inflation factor)
- ✓ Independence (Residuals Plot)

SAMPLE 1: 59 tubular joints of 16 mm

Same specimens that were used for the T' curve



Regression Curve 1: $logN_3 = 12.386 - 2.761\ log\Delta\sigma$

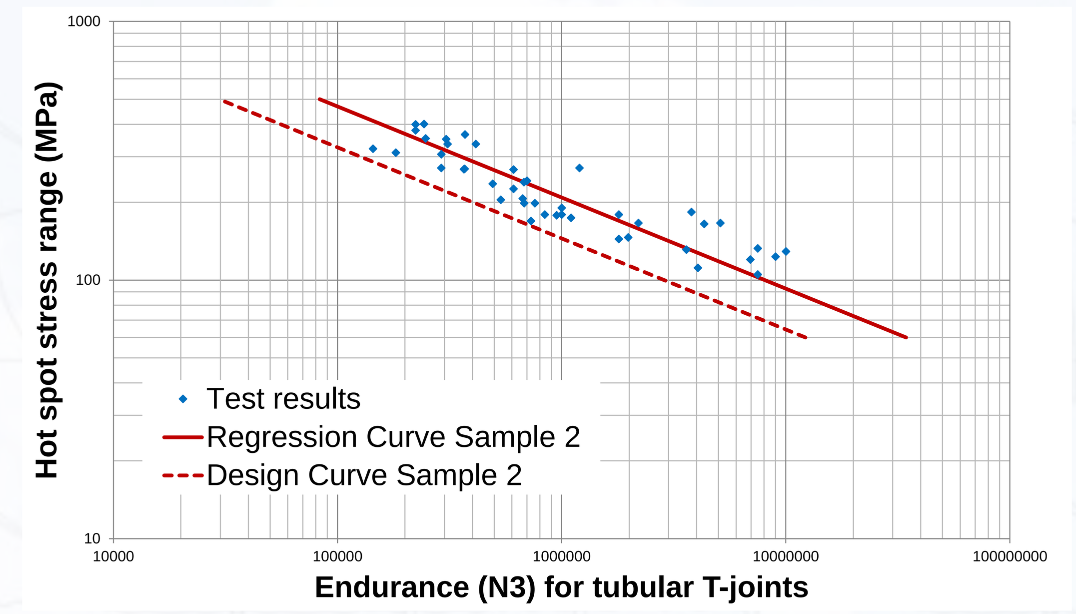
Design Curve 1: $logN_3 = 11.931 - 2.761\ log\Delta\sigma$

Thickness Correction: $\Delta\sigma = \Delta\sigma_o \cdot (\frac{16}{T})^{0.25}$

If the Design Curve 1 is taken to be that corresponding to a 6.68% probability of failure, instead of 2.3%, there will be an endurance of 5.21 million cycles (more than a year).

SAMPLE 2: 44 tubular T-joints of 16 mm

Only the T-shaped specimens of Sample 1



Regression Curve 2: $logN_3 = 12.588 - 2.841\ log\Delta\sigma$

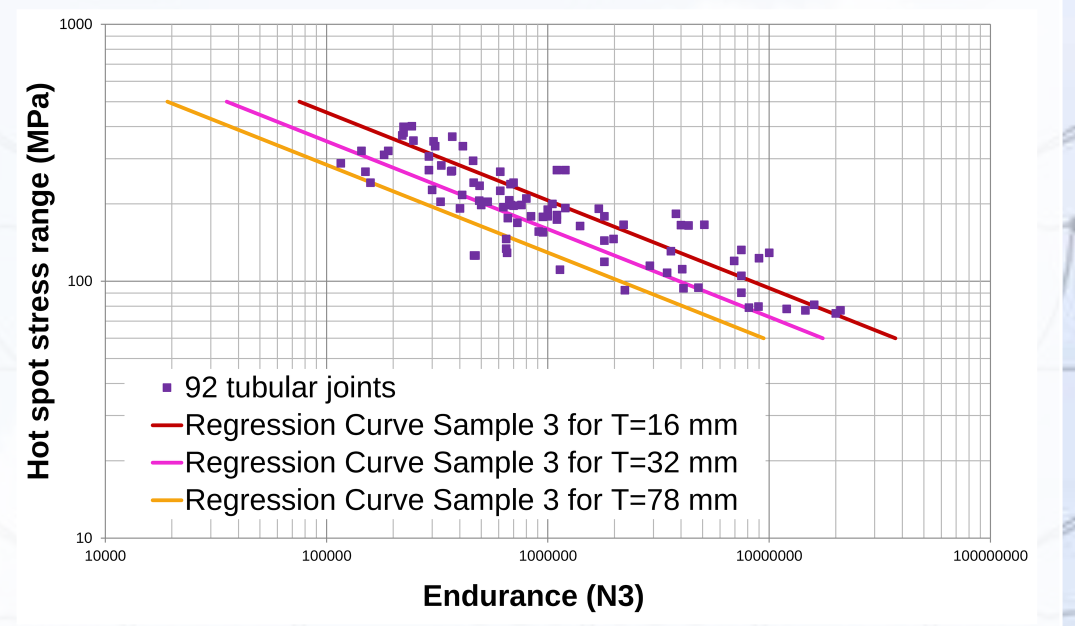
Design Curve 2: $logN_3 = 12.139 - 2.841\ log\Delta\sigma$

Thickness Correction: $\Delta\sigma = \Delta\sigma_o \cdot (\frac{16}{T})^{0.25}$

There are not enough specimens of each loading case.
Two variable transformations were analysed, the residual sum of squares (RSS) is lower for the Log-transformation than for the Box-Cox transformation.

SAMPLE 3: 92 tubular joints

All the specimens from the UKOSRP and ECSC programme

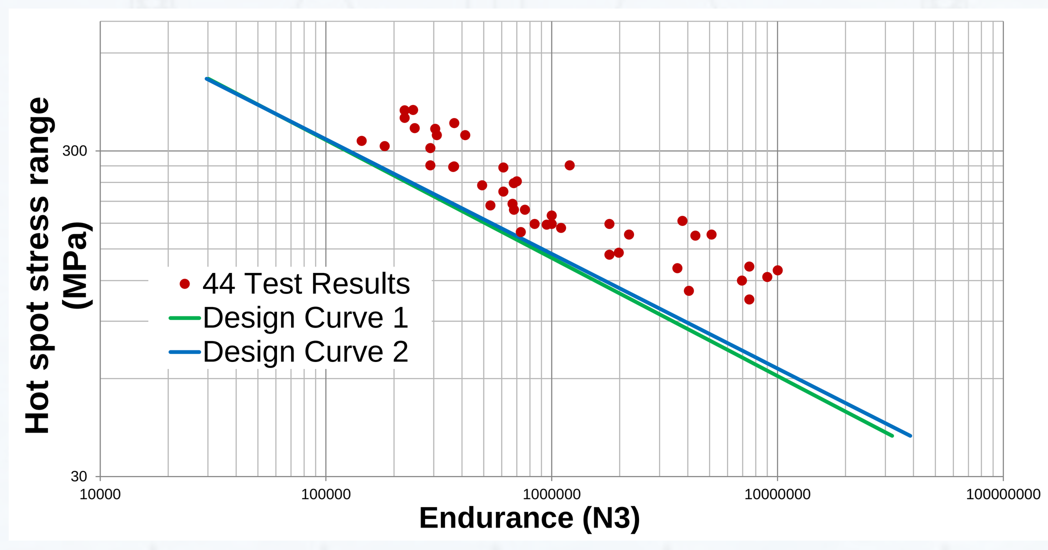


Regression Curve 3: $logN_3 = 11.133 - 2.925 log\Delta\sigma + 1.973\frac{1}{log\ T}$

Design Curve 3: $logN_3 = 10.667 - 2.925\ log\Delta\sigma + 1.973\frac{1}{log\ T}$

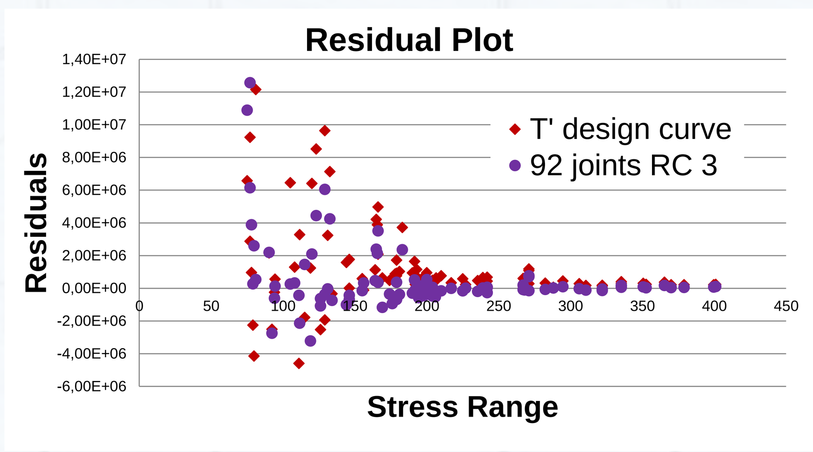
83.2% of the variance in fatigue life can be predicted by combination of stress range and thickness.

Discussion

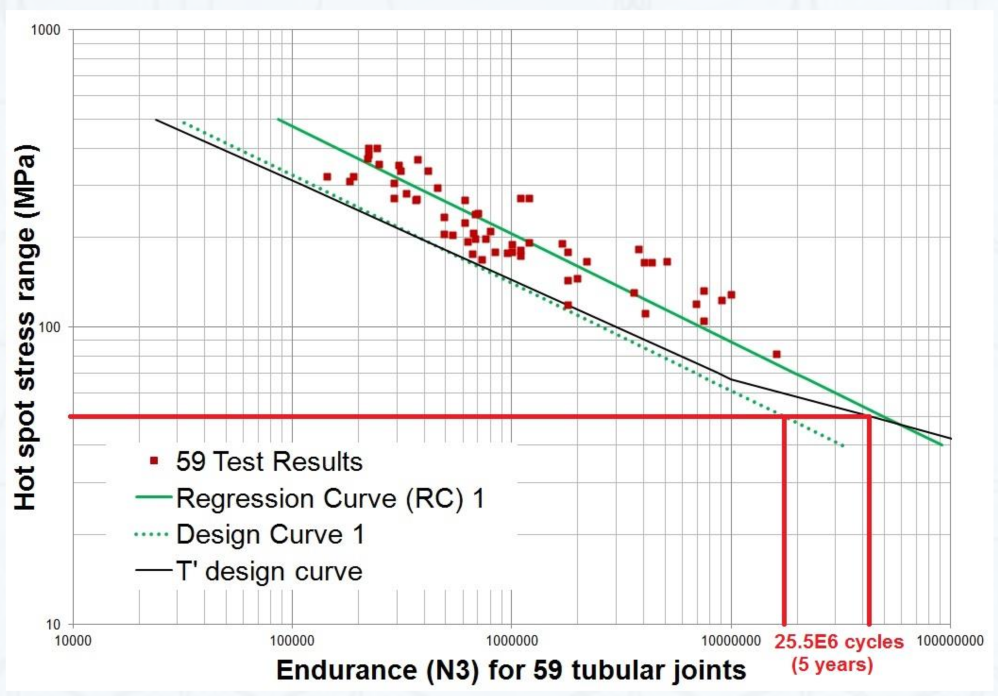


The lifespan of Regression Curve 1 is impaired by failing to distinguish between intersections.

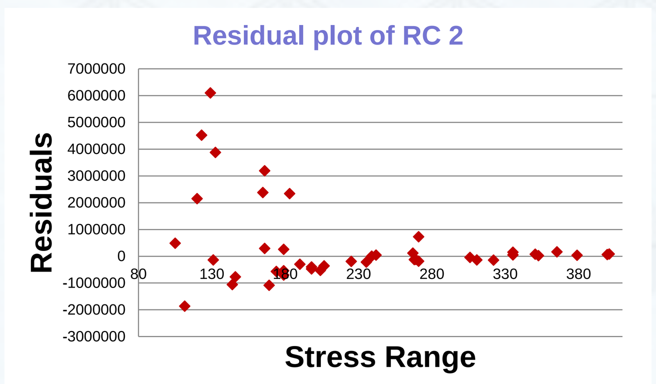
Regression Curve 3 is more reliable than the T' curve since the number of specimens is much greater. Therefore, it may not be required a design curve of 2.3% of failure.



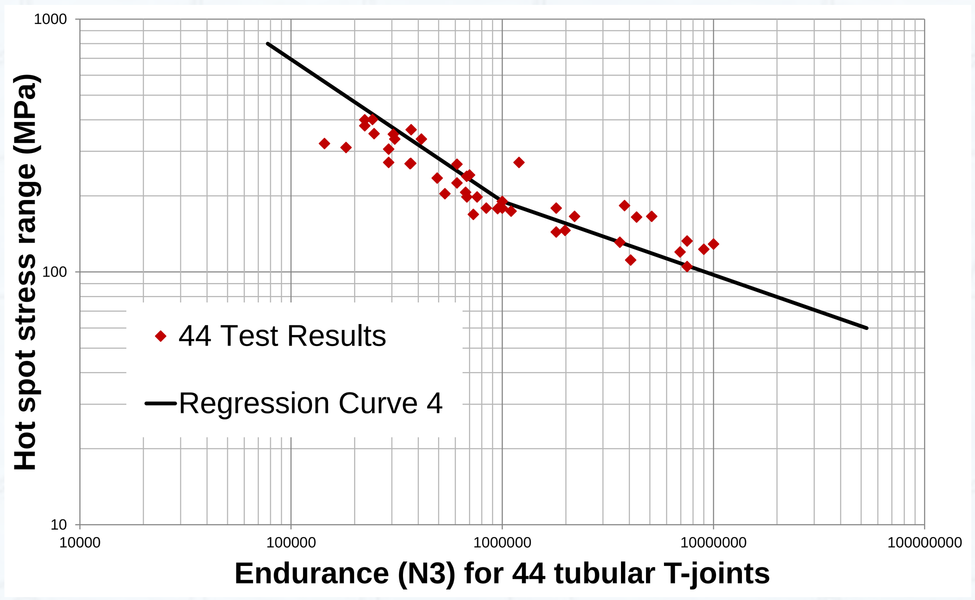
The average value of the residuals has decreased although it has more over-predictions, but all of them are lower than 2 million cycles (i.e. an over-estimation lower than a year).



The slope of the T' design curve was rounded to 3 in order to retain consistency with earlier Guidance [1].
All test results had a relatively short lives (<10 million cycles).
T' design curve below a HSS range of 190.7 MPa increase the probability of failure.



The difference between the observed values and the predicted values increases significantly below 190 MPa, the sample was divided into two groups and a new regression analysis was performed. The RSS was reduced considerably.



Regression Curve 4:

$logN_3 = 10.063 - 1.782\ log\Delta\sigma \qquad \Delta\sigma > 190\ MPa$

$logN_3 = 13.848 - 3.443\ log\Delta\sigma \qquad \Delta\sigma < 190\ MPa$

Conclusions

It would be convenient to:
- include all the available data in the regression analysis for increasing the reliability,
- have different curves for each type of joint configuration,
- carry out an assessment about the probability of failure for deriving design curves,
- study the slope curve above the endurance limit because may need some modification,
- consider different subsets divided according stress levels, and
- include at least the thickness as an independent parameter in the regression analysis.

Recommendations

The results of this study should not be used to assess fatigue, further research must be carried out for the development of new S-N curves to reduce safety factors and thus reduce costs, without incurring in an unnecessary increase of the probability to failure.

References

1. **Health and Safety Executive.** *Background to new fatigue guidance for steel joints and connections in offshore structures.* Offshore Technology Report - OTH 920390