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Review of fatigue data for welds improved by tungsten inert gas dressing

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ABSTRACT

Experimental fatigue data points for the welds improved via the tungsten inert gas (TIG) dressing method have been extracted from the existing literature. The extracted fatigue data includes experimental points for longitudinal attachments, transverse non-load carrying welds, butt joints and T-joints. In total, 311 published test results for weld details with various yield strengths ($272 \leqslant f_y \leqslant 1100$ MPa) and stress ratios ($-1 \leqslant R \leqslant 0.2$) are presented and analysed. A step-wise increase in the fatigue strength based on the specimen geometry and the steel grade is proposed with an *S–N* slope of $m_1 = 4$. All of the fatigue data for constant amplitude loading are found to be in good agreement with respect to the proposed design curves.

1. Introduction

Structures and components that are subjected to severe dynamic loading may experience fatigue damage at welded joints during their lifetime. Global trends, such as lightweight design for better fuel economy and extended life span for sustainability, present challenges for engineers who investigate dynamically loaded components. One economical solution for overcoming this difficulty is to utilise high strength steel (HSS) structures in engineering design. However, the use of HSS is limited in practice due to the fatigue properties of welds, which are only equivalent to those of lower strength steel grades [1]. Therefore, some additional techniques are required before structures and components can more fully benefit from HSS. One option for solving this issue is to use fatigue strength improvement methods for welded joints.

Various weld toe treatment methods have been developed for improving the fatigue performance of welded components. Some of the treatment methods are applied during the welding process, whereas others may need additional operation after welding. Low-transformation-temperature (LTT) weld filler material is a good example of a way to reduce the detrimental effects of tensile residual stresses during welding [2,3]. On the other hand, other techniques, such as post-weld treatment methods, are becoming more popular for both increasing the fatigue strength of new structures and repairing existing structures. In general, post-weld treatment methods can be divided into two groups: weld profile modification methods and weld residual stress modification methods [4]. The goals of the former methods are (i) to remove or reduce the size of the weld toe flaws, which may result in an extended crack initiation phase for the fatigue life, and (ii) to reduce the local stress concentration due to the weld profile by achieving a smooth transition between the plate and weld face. The best-known weld profile modification methods are machining or grinding of the weld seam and toe and re-melting the weld toe by TIG, plasma or laser dressing. For the weld residual stress modification methods, the main aim is to eliminate the high tensile residual stress in the weld toe region and to induce compressive residual stresses at the weld toe [4]. Hammer and needle peening are two of the best-known methods. Besides these methods, high-frequency mechanical impact (HFMI) technologies have also received significant attention and increased in importance during the past twenty years. A great basis for HFMI treatments is that the fatigue strength increases due to the treatment as the steel grade of the treated material increases [5].

In this review study, the fatigue strength of welded joints improved by a weld profile modification method has been investigated. The guiding theory, previously reported literature data, the latest concepts and practical recommendations on using the tungsten inert gas (TIG) dressing technique for design purposes have all been compiled together.

2. Tungsten inert gas dressing

To improve fatigue strength by TIG dressing, standard TIG welding equipment is used to re-melt the existing weld metal in order to obtain a shallow depth along the weld toe [6]. This process is

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Nomenclature

f_y	yield strength
k	number of specimens in series
CAL	constant amplitude loading
FAT	the IIW fatigue class, i.e. the nominal stress range in mega pascals corresponding to 95 survival probability at 2×10^6 cycles to failure (a discrete variable with 10–15 increase in stress between steps)
IIW	International Institute of Welding
HSS	high strength steels
TIG	tungsten inert gas
VAL	variable amplitude loading
ΔS	stress range
ΔS_i	stress range for specimen i
ΔS_k	characteristic value corresponding to 95 survival probability at 2×10^6 to failure
ΔS_m	mean value corresponding to 50 survival probability at 2×10^6 to failure
σ_N	standard deviation in life
$\hat{\sigma}_N$	estimate of the normal distribution variance
m_1	slope of the S–N line for stress cycles above the knee point
m_2	slope of the S–N line for stress cycles below the knee point
R	stress ratio ($\sigma_{min}/\sigma_{max}$)
N	number of cycles
X_N	improvement factor in life for welds improved by TIG dressing at ΔS equal to the FAT class of the as-welded joint: $N_f = X_N \times 2 \cdot 10^6$

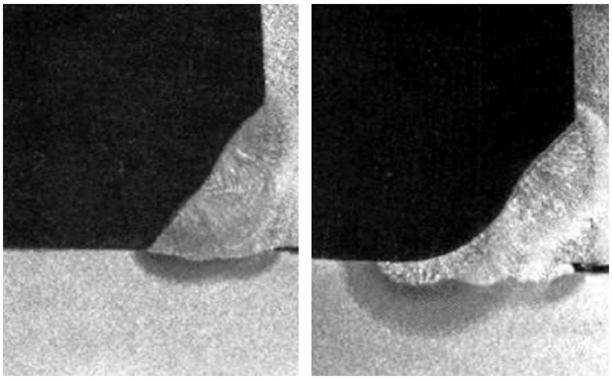

Fig. 1. Typical weld toe profile in the as-welded condition and following TIG dressing [4].

performed without the addition of filler material and it results in reduced weld flaws. The most important benefit of the re-melting process is that a smooth transition from the weldment to the base material is achieved. This in turn reduces the stress concentration at the dressed region so that the fatigue strength of the welded joint increases. For example, Fig. 1 shows a typical fillet weld toe profile in the as-welded condition and the subsequent TIG dressing condition. As a general observation, TIG dressing is quite sensitive to the surface condition of the material, therefore close attention should be paid to removing any, e.g. rust, oil and paint [4,7–9] from the material. Insufficient cleaning will result in reduced fatigue performance due the formation of gas pores. Additionally, other parameters affecting the fatigue strength due to the re-melting process include, for instance, travel speed, the welding current and the position of the torch as well as the shielding gas [10]. Typical conditions and the range of dressing parameters can be found in the International Institute of Welding's (IIW) recommendations for improving the fatigue strength of welded structures [4].

3. Methods

3.1. Extracted fatigue data

Eighteen publications dealing with the fatigue data points for welded steel joints improved via the TIG dressing method were identified. Some of the identified studies reported on multiple materials with various steel grades. So, a total of 311 data points from 36 data sets for the four most commonly used specimen types were reviewed. Some of the references present fatigue data points in the form of a table. However, many of the references provide fatigue data only as points on a graph. When the numerical values of fatigue data points were not reported explicitly, open source software was used to extract the data.

The investigated specimen types included longitudinal attachments, transverse non-load carrying welds, butt joints and T-joints. T-joints were loaded in a bending manner, whereas the others were loaded axially. Most of the tests were performed under constant amplitude loading, while a limited number of tests were performed using variable amplitude loading. Nevertheless, these results have also been reported. The fatigue data are summarised in Tables 1–4. Run-outs were excluded. The yield stress of steel grades varies from 272 to 1100 MPa, and the specimen thickness varies from 3 to 25 mm. Thickness correction method according to the IIW guidelines was applied, whereas no yield strength and stress ratio correction method were considered for TIG dressing in this study. Only weld toe failures were taken into account, with the exception of a study by van Es et al. [10]. In their study, a few base material and weld material failures were observed for cast and rolled steels. Nevertheless, those data points were also considered in this study because of the lack of improved butt joint test data and the validation of similar fatigue life for cast and rolled steels [11].

Tables 1–4 show the steel type, the specimen type, the plate thickness and the R ratio for each data set. The number of test specimens, k, and best-fit S–N slope based on linear regression are also reported. The FAT class of each specimen type is taken from the IIW Recommendation [12] and the stress range corresponding to 50% survival probability for as-welded specimens at $N = 2 \times 10^6$ are typical values used by the International Institute of Welding [13]. These values were calculated as $\Delta S_m = 97$ MPa for longitudinal attachments, $\Delta S_m = 110$ MPa for transverse non-load carrying welds and T-joints, and $\Delta S_m = 123$ MPa for butt welds [14] by using $\sigma_N = 0.206$. In some of the references given in Tables 1–4 the material yield strength, f_y, of the specimens is not reported. In such cases, values were taken from the published datasheets [15]. The last four columns in Tables 1–4 show the fatigue strength and the calculated fatigue strength improvement with respect to 50% failure probability. The stress range for the fatigue strength improvement (%) was computed assuming both a fixed S–N slope of $m_1 = 4$ and based on the best-fit regression line for the respective data set.