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Influence of post-weld improvement on fatigue strength of butt-weld in different steel grades

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Abstract

The IIW recommendations for Fatigue Design of Welded Joints and Components published in 2024 define four fatigue classes for butt welds that are welded from two-sides (details 211, 212, and 213) depending on the misalignment quality, the weld bead geometry and whether the weld is ground flush. As with other finishing techniques (HFMI, TIG dressing) where the steel grade is considered, flush grinding could allow for taking advantage of improved fatigue properties.
In this study, fatigue tests were conducted with S355, S460 and S690 butt-welds with misalignments of 5% (Case 212) and 10% (Case 213), as well as with toe grinding (Class B125 of ISO 5817) and flush grinding (Case 211) to assess the effect of the quality improvement on the fatigue strength.
In the as-welded condition, reducing the misalignment to 5% does not necessarily lead to a significant improvement in fatigue performance compared to larger misalignments as the quality of the weld toe is a primary factor in the fatigue strength.
The B125 quality can easily be achieved by grinding the weld toe, resulting in a local transition radius well above 4 mm.
As expected, flush grinding greatly improves the fatigue life of the welds, exceeding that of case 211 (FAT125, m=5). Moreover, this improvement is sensitive to the grade of the base material as are other finishing techniques.

Keywords

Butt-weld, Fatigue, Grinding, HS Steel

1. Introduction

One of the main ways to reduce manufacturing costs is through the reduction of base material purchasing costs. Fatigue design of structures generally leads to a significant increase in cross-sectional areas (or moments of inertia) in order to reduce local stresses, since current design codes do not allow the mechanical advantage of higher yield strength materials to be fully exploited.

From an industrial perspective, it would be desirable to rely on specific requirements for high-strength steels (HSS) used in butt-welded plates or shell structures, enabling structural optimization compared with conventional structural steels having a yield strength (YS) lower than or equal to 355 MPa.

The latest edition of EN ISO 5817 introduced specific requirements for improved quality levels allowing the use of higher fatigue classes. Depending on weld profile geometry, a fatigue class 125 may be assigned. It is worth noting that this fatigue class is surprisingly higher than the maximum fatigue class currently associated with flush-ground butt welds according to IIW recommendations, namely FAT112. Furthermore, EN 13001-3-1+A2 for the design of lifting equipment provides a fatigue class FAT140 for butt welds when the weld complies with quality level B*. This B* quality level is defined by compliance with flush-grinding requirements, a misalignment lower than 5%, and the absence of volumetric imperfections. Eurocode 3 as well as Section C11 of CODAP do not permit differentiation of fatigue detail categories according to steel grade, such as S420NL, S460NL or S460M, combined with specific requirements (welding procedure, execution quality levels, post-weld finishing), which could allow higher fatigue strengths to be achieved with an acceptable level of reliability. This absence of differentiation according to mechanical properties remains even after flush grinding, which is at variance with recent findings.

It should also be noted that the requirements associated with detail categories 211 and 212 are more or less consistent with informative Annex B of EN ISO 5817. In this annex, quality class B90 allows a misalignment limit of 10%, whereas a limit of 5% is normally required in IIW document XIII-2151r4-07 / XV-1254r4-07 to justify FAT90. A misalignment of 10% is normally associated with FAT80.

However, according to IIW recommendations, FAT125 is associated with weld profile improvement by grinding, whereas informative Annex B of EN ISO 5817 associates quality level B125 only with weld profile dressing requirements imposing a transition angle greater than 150° and a transition radius greater than 4 mm. Consequently, a designer selecting FAT90 should impose manufacturing requirements exceeding those of quality level B according to EN ISO 5817.

The objective of this study is to quantify the fatigue improvement achievable through flush grinding of butt welds, namely whether performance corresponding to FAT112 or FAT140 can be reached and, if applicable, to highlight a potential effect of steel grade by carrying out the investigation on different steel grades using matching filler metals capable of ensuring the yield strength of the base metals within the weld metal.

2. Methods

2.1. Materials and specimens

To achieve this objective, an experimental programme was carried out on butt welds produced by the submerged arc welding process (SAW, process 121), including:

- Different levels of misalignment (5% and 10%) to assess the influence of fit-up quality on the fatigue performance of a standard welded joint;
- Flush-ground welds to investigate the geometrical effect on weld quality and the influence on the slope of the fatigue curve;
- Weld toe burr grinding to determine the difference in behaviour between flush grinding and weld toe burr grinding;
- Different thicknesses, including one configuration with reduced thickness based on the square root of the yield-strength ratio to account for bending loading, considering that the moment of inertia is proportional to the square of the thickness.

The selected misalignment levels were chosen according to the recommendations of document IIW-2259-15 XIII-3004-2023 / XV-1649-2022, which define different fatigue classes depending on misalignment levels of 5% (Cases 211 and 212) or 10% (Case 213).

The configurations listed in Table 1 were selected to verify compliance with the recommendations concerning misalignment and to assess the effect of an increase in yield strength.

Table 1. Description of the tested configurations

Steel grade	Expected Fat Class	S355	S460		S690
Filler product		S3Si1	S4Mo		S3NiCrMo2,5
Thickness (mm)		18	18	16	18
Standard misalignment (10%) – as-welded condition	FAT80 m = 3	B-S355-18-10 24 samples	-	-	-
Reduced misalignment (5%) – as-welded condition	FAT90 m = 3	B-S355-18-5 24 samples	-	-	-
Reduced misalignment (5%) + weld toe burr grinding	B125 m = 5	-	-	E-S460-16-5 26 samples	-
Reduced misalignment (5%) + Flush grinding	FAT125 m = 5	A-S355-18-5 25 samples	A-S460-18-5 26 samples	A-S460-16-5 25 samples	S-S690-16-5 26 samples

Each welded assembly was produced using submerged arc welding with a fixture designed to minimize angular misalignment.

Flush grinding was performed using a polishing disc with grit size 40–60 followed by a final surface finishing operation using grit size 120. The objective was to remove the scratches generated during the initial grinding operation and eliminate the weld reinforcement, in accordance with IIW document XIII-2200r4-07. Grinding was carried out parallel to the weld axis. Visual and magnetic particle inspections were performed to ensure complete removal of the weld toes and any undercut defects, as well as the absence of cracks. In accordance with the same recommendations], weld toe burr grinding was carried out using a rotary burr with a minimum diameter of 20 mm.

Approximately twenty specimens were extracted from each welded assembly. Rectangular specimens were used for as-welded joints, whereas dog-bone specimens were machined from flush-ground joints to promote fracture within the region of interest.

2.2. Measurement of Specimen Geometry

After sampling, each specimen was laser scanned to characterize both its global and local geometry, including:

- Measurement of the local weld toe radius in the as-welded condition;
- Measurement of weld misalignment;
- Measurement of groove depth and radius in the case of weld toe burr grinding.

2.3. Estimation of Stress Concentration Factors

Stress concentration factors were also determined by three-dimensional finite element analyses performed on each specimen using Abaqus software. A tensile load of 200 kN was applied. The resulting stress field was extracted along the width of each weld toe to calculate the numerical stress concentration factor (K_t) according to:

$$K_t = \frac{\sigma_{EF}}{\sigma_{nom}} \qquad \text{Equation 1}$$

Where :

- σ_{EF} the stress obtained from finite element analysis (maximum absolute principal stress);
- σ_{nom} the nominal stress calculated from

$$\sigma_{nom} = \frac{F}{S} \qquad \text{Equation 2}$$

where F is the applied force and S is the load-carrying cross-sectional area.

For each specimen, the numerical stress concentration factor corresponds to the maximum value obtained from a moving average calculated over ±2.4 mm around each position along the width of the specimen.

2.4. Fatigue testing

Part of the fatigue testing programme was conducted at CETIM, while the remaining tests were subcontracted to Fraunhofer LBF (Germany). Test conditions were as follows:

- 250 kN and 450 kN hydraulic test machines (CETIM) for the as-welded and burr-ground configurations using straight specimens (50 mm width) and fatigue testing machine (Fraunhofer LBF) for flush-ground configurations using dog-bone specimens;
- Spherical loading grips were used to accommodate the intended misalignment;
- Load-controlled testing;
- Stress ratio: R=0.1;
- Test frequency: 8–10 Hz;
- Run-out criterion: 5 million cycles;
- Failure criterion: complete fracture of the specimen.

Fatigue results were analysed using Basquin's law:

$$\log(N) = \log(C) - m.\log(\Delta\sigma) \qquad \text{Equation 3}$$

Where :

- N: number of cycles to failure ;
- Δσ : the stress range ;
- C and m: parameters determined by linear regression.

The fatigue curves were statistically evaluated for a survival probability of 95% with a confidence interval of 75%. This approach allows the determination of FAT classes, i.e. the allowable fatigue strength at 2 million cycles.

3. Results and discussion

3.1. Weld Toe Geometry Quality

The quality of the weld toe transition was evaluated for the as-welded and weld toe burr-ground configurations by measuring the weld toe radius and weld toe angle (Fig. 1 to Fig. 3).

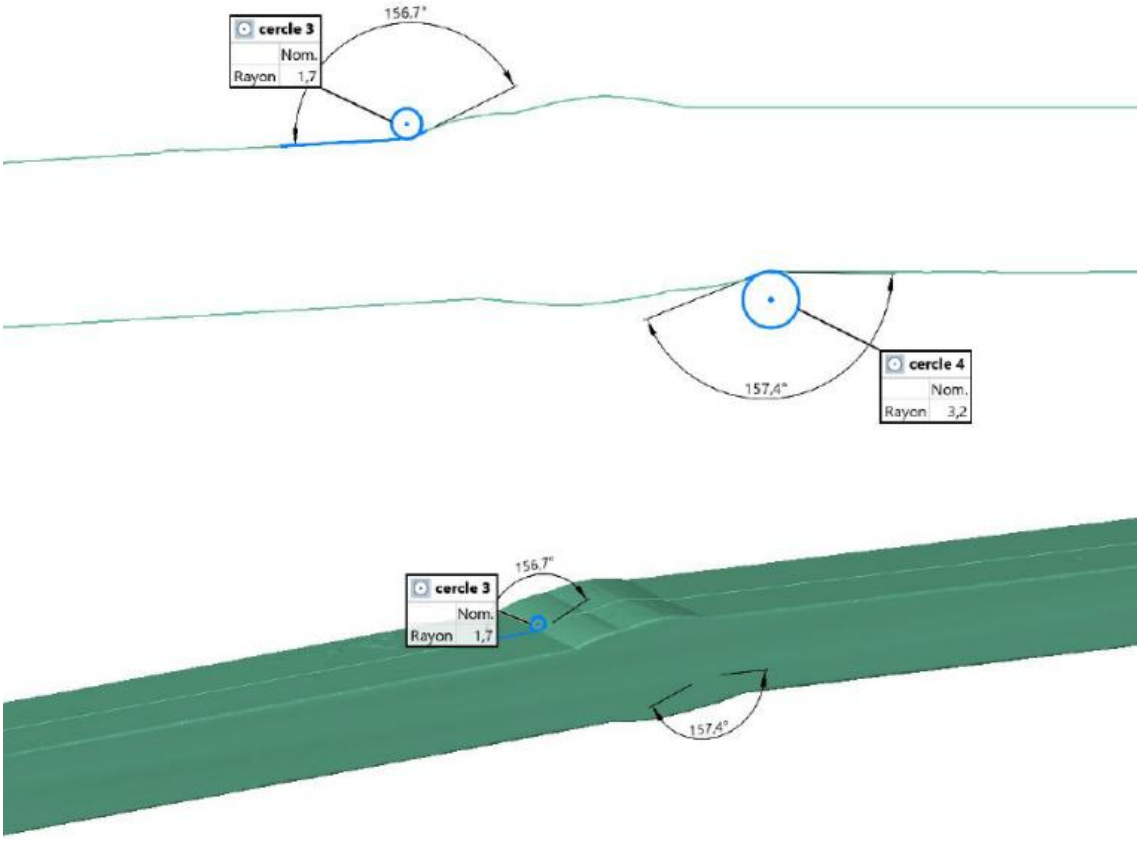


Fig. 1 S355 – Misalignment 10% - As-Welded condition – Sample A-S355-18-10-12 – Toe angle and radius measurement

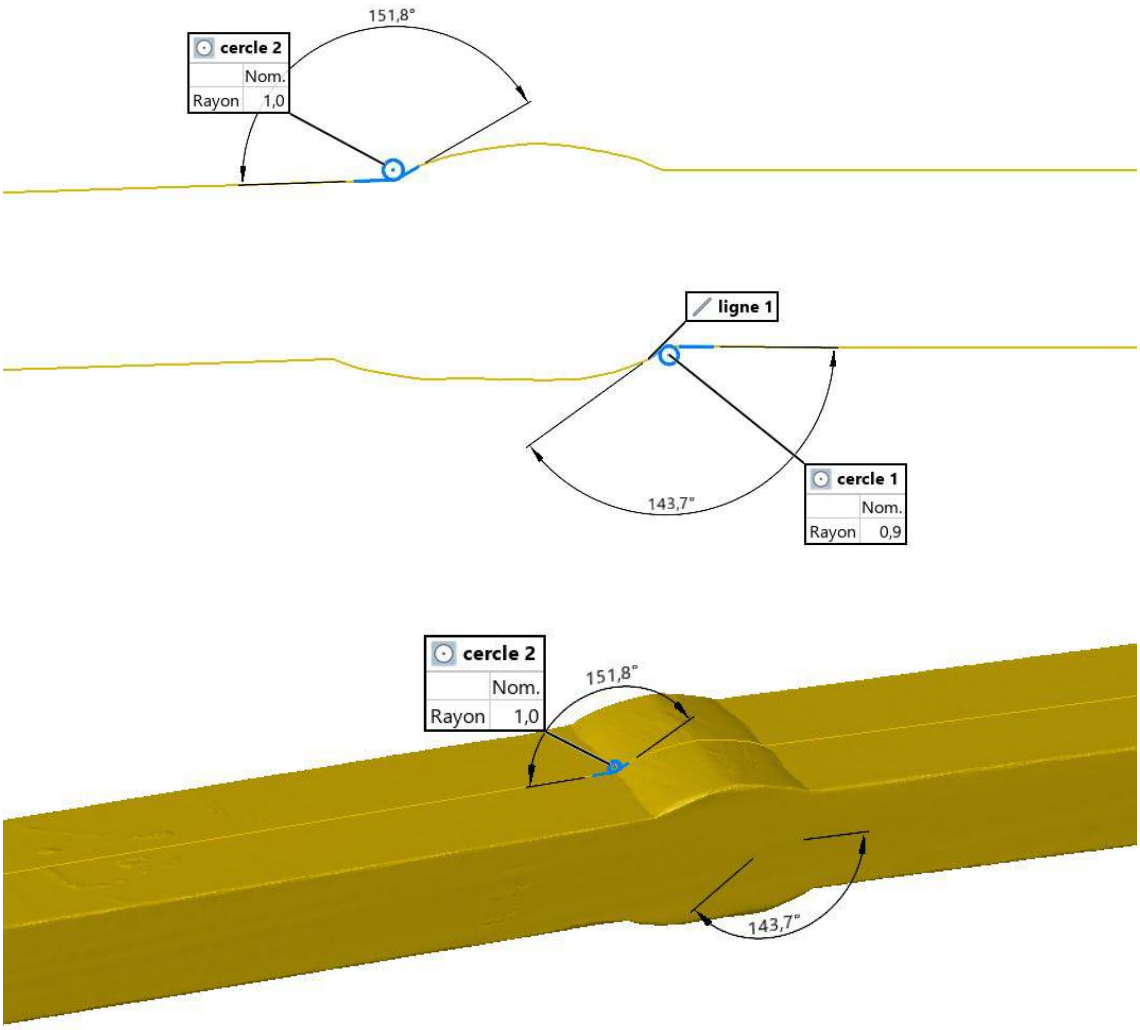


Fig. 2 S355 – Misalignment 5% - As-Welded condition - Toe angle and radius measurement

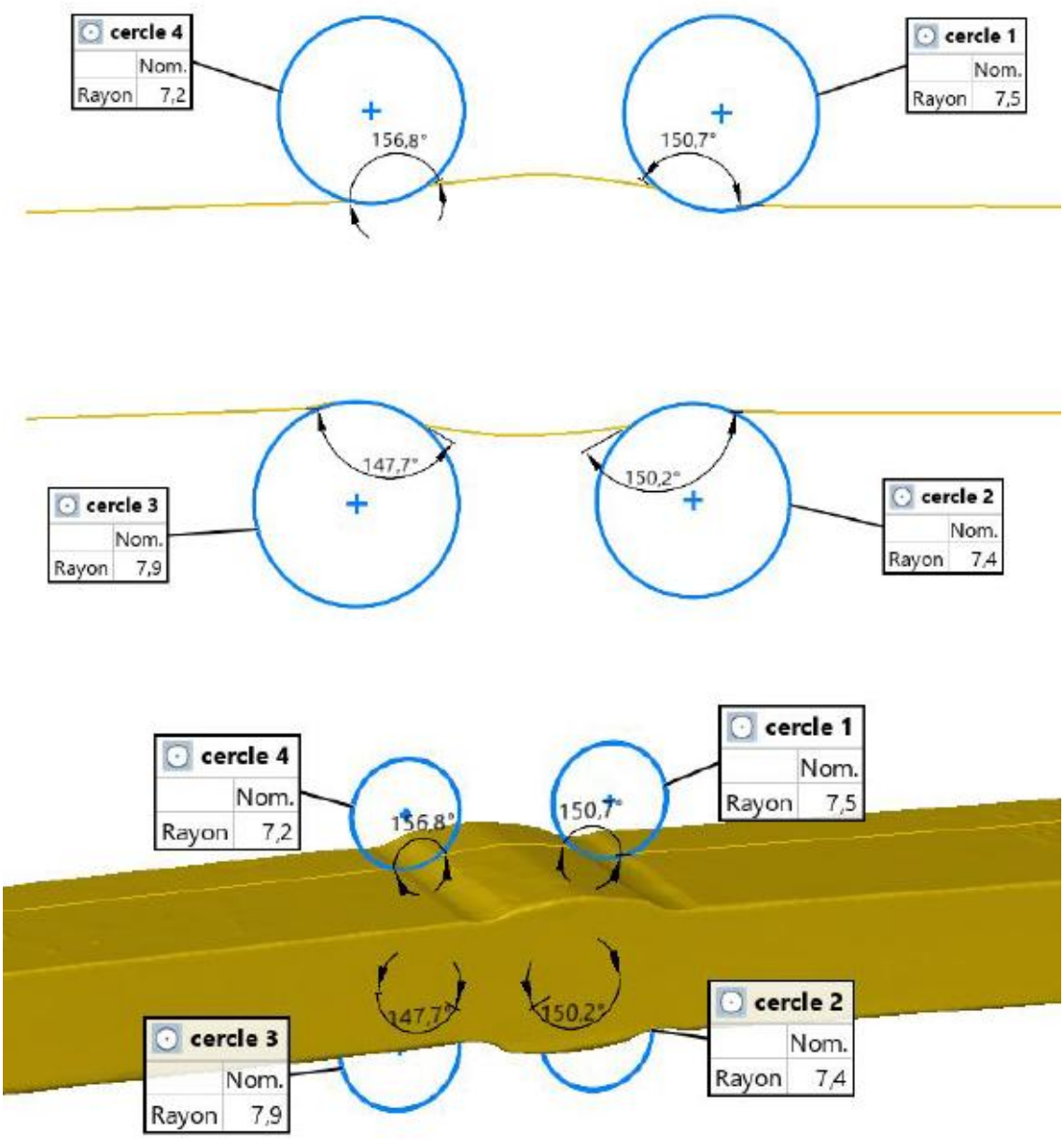


Fig. 3 S460 – Misalignment 10% - Toe burr grounded condition – Sample E-S460- 16-5-16 – Toe angle and radius measurement

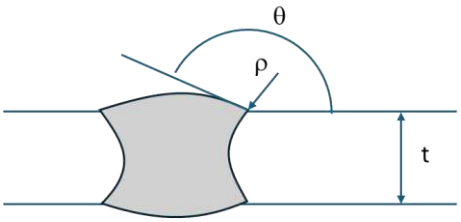
For the as-welded specimens, the welding deposition strategy, which was influenced by the level of misalignment, resulted in different weld toe geometries (Table 2). However, in both configurations, the weld profile quality complied with Quality Level B of EN ISO 5817. Considering the additional requirements specified in Informative Annex B of this standard, Quality Level B90 was achieved for the 10% misalignment configuration, whereas the 5% misalignment configuration was at the acceptance limit with respect to the toe radius requirement. The requirements for B125 were only partially fulfilled by the specimens subjected to weld toe burr grinding, since the toe angle was occasionally slightly below the required value of 150°.

Table 2. Weld toe geometry quality obtained for the investigated configurations

	Quality Level B	Quality Level B90	Quality Level B125	10% Misalignment	5% Misalignment	Weld Toe Burr Ground
Toe angle	≥ 110°	≥ 110°	≥ 150°	157°	144° - 152°	148° - 157°
Toe radius	Not specified	≥ 1 mm	≥ 4 mm	1.7 – 3.2 mm	0.9 – 1.0 mm	7.2 – 7.4 mm

It should be emphasized that weld toe quality is strongly influenced by welding conditions. In the present study, the natural slope imposed by the higher level of misalignment resulted in an improved weld toe transition. The local weld toe quality may be estimated using the analytical expressions proposed by Lawrence and Anthes.

Equation 4. Analytical expressions for local stress concentration factors at the weld toe of butt welds



$$K_t = 1 + 0{,}27 \cdot tan(\pi - \theta)^{1/4} \cdot \left(\frac{t}{\rho}\right)^{1/2}$$

$$K_t = 1 + 0{,}7{,}28 \cdot sin(\pi - \theta)^{0{,}932} \cdot \left(\frac{t}{\rho}\right)^{0.382}$$

Both analytical equations provide very similar results and clearly highlight the strong influence of the weld toe radius. Consequently, in the present case, the 5% misalignment configuration produced a less favourable weld toe geometry and therefore generated a higher local stress concentration factor than the 10% misalignment configuration (Table 3). It should be noted that this observation may not necessarily be applicable to other welding conditions or plate thicknesses, where the final capping passes could result in comparable toe geometries even for 10% misalignment.

Table 3. Influence of weld toe geometry on notch-induced stress concentration factors

Steel grade	Misalignment	Condition	Toe angle (°)	Toe radius (mm)	$K_{t\ Lawrence}$	$K_{t\ Anthes}$
S355	10%	As-welded	157	1.7	1.7	1.7
S355	5%	As-welded	145	0.9	2.1	2.4
S460	5%	Weld toe burr ground	150	7.5	1.3	1.5

3.1.1. Combined Effect of Notch Stress Concentration and Misalignment

The combination of notch stress concentration and misalignment results in relatively similar local stress conditions for the two as-welded configurations, although the specimens exhibiting 5% misalignment are slightly penalized. As shown in Table 4, weld toe geometry plays a predominant role. Beyond the effect of misalignment, the quality of the weld toe transition, and particularly the toe radius, becomes the governing parameter.

Table 4. Influence of weld toe geometry on the combined stress concentration factor (k_m according to [6])

Steel grade	Misalignment	Condition	*Kt* Lawrence	*Kt* Anthes	*km*	$1 + (km - 1) + (kt - 1)$
S355	10%	As-welded	1.7	1.7	1.3	2.0
S355	5%	As-Welded	2.1	2.4	1.15	2.25 to 2.55
S460	5%	Weld toe burr ground	1.3	1.5	1.15	1.45 to 1.65

3.1.2. Estimation of Stress Concentration Factors by Finite Element Analysis

Table 5 illustrates the numerical simulations performed for three representative welded configurations:

- S355, 18 mm thickness, 10% misalignment;
- S355, 18 mm thickness, 5% misalignment;
- S460, 16 mm thickness, 5% misalignment after weld toe burr grinding.

The finite element calculations confirm that, beyond the influence of weld misalignment itself, the notch effect is strongly governed by weld toe geometry. The poorer toe transition measured on the 5% misalignment specimens resulted in higher stress concentration factors. Conversely, weld toe burr grinding reduced the stress concentration factor owing to the smooth groove produced during the treatment (Table 6).

Furthermore, the ratios obtained from finite element analysis are in very good agreement with those determined analytically. The trend previously identified, namely that the larger misalignment unexpectedly resulted in a more favourable local weld geometry, is consistently observed regardless of the assessment method used.

Table 5. Illustration of stress concentration factors for the as-welded and burr ground specimens

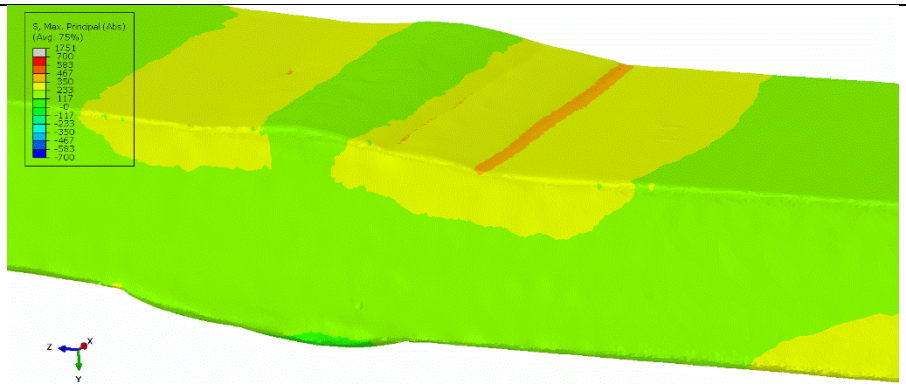
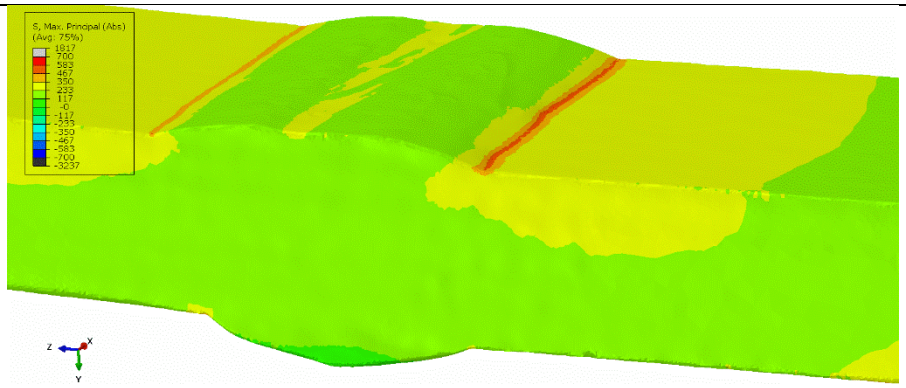
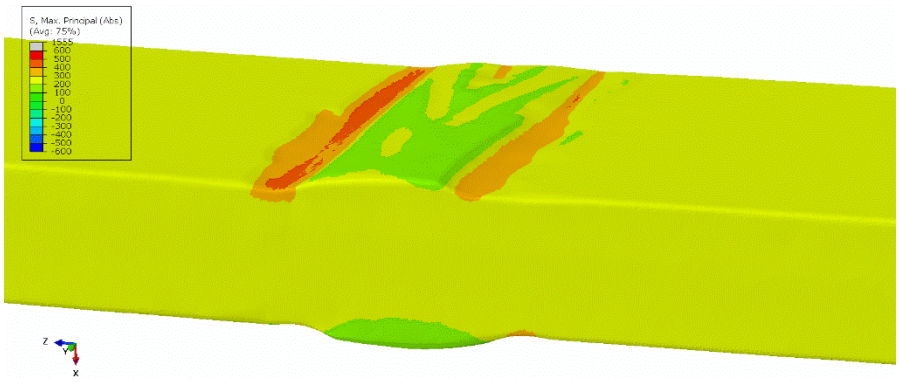
Condition	Stress field distribution
S355 Misalignment 10% As-welded condition Specimen B-S355-18-10-12	 (a)
S355 Misalignment 5% As-welded condition Specimen B-S355-18-5-05	 (b)
S460 Misalignment 5% Toe burr grounded condition Specimen E-S460-16-5-1	 ©

Table 6. Variation of stress concentration factors

Steel grade	Thickness (mm)	Misalignment	Condition	W1	W4	Average ratio	Analytical ratio (Table 4)
S355	18	10%	As-Welded	2.3	1.8	1 (*)	1 (*)
S355	18	5%	As-Welded	2.9	2.0	1.20	1.13 to 1.28
S460	16	5%	Weld toe burr ground	2.0	1.4	0.83	0.73 to 0.83

(*) Reference configuration used for normalization of stress concentration factors

3.2. Fatigue Testing

3.2.1. Establishment of S-N curves

The mean S–N curves (corresponding to a 50% probability of failure) were established using the Basquin's model, fitted from valid failed test results according to the following equation:

$$N = \log(C) - m.\log(\Delta\sigma) \qquad \text{Equation 5}$$

Where

$\Delta\sigma$	nominal stress range (MPa),
$\log(C)$ et m	the parameters of the Basquin's relationship

The design S–N curve was defined as the curve corresponding to a 95% survival probability with a 75% confidence interval. The associated Basquin's constant is denoted log(Ck). The parameters of the design S–N curves are given in Table 7 for each configuration.

Table 7. Parameters of the Basquin's equation used to establish design S–N curves and associated FAT classes (allowable stress range at 2 million cycles)

	B-S355-18-10	B-S355-18-5	E-S460-16-5	A-S355-18-5	A-S460-16-5	A-S460-18-5	A-S690-18-5
Steel grade	S355	S355	S460	S355	S460	S460	S690
Misalignment	10%	5%	5%	5%	5%	5%	5%
Post-weld treatment	As-welded	As-welded	Weld toe burr ground	Flush ground	Flush ground	Flush ground	Flush ground
m	4.4	3.7	4.4	*10.0* *	12.3	9.9	6.6
log *C*	15.175	13.728	16.187	*31.094*	37.804	31.778	23.133
s_{logC}	0.218	0.102	0.170	*0.563*	0.269	0.236	0.214
logCk	14.666	13.491	15.781	*29.566*	37.136	31.118	22.552
Calculated FAT class	80	80	125	*212*	324	314	292

** The slope exponent was fixed with m = 10 because the number of valid test results was insufficient and too scattered to allow a reliable estimation by linear regression.*

3.2.2. As-Welded S355, 18 mm Thickness, 5% and 10% Misalignment

Fig. 4 presents the fatigue test results obtained on 18 mm thick butt-welded S355 specimens with misalignment levels of 10% and 5%. Consistent with the observations discussed previously, the lower misalignment level resulted in a less favourable local weld geometry (smaller toe radius and lower toe angle), thereby offsetting the beneficial effect normally expected from reduced misalignment. Consequently, both populations exhibit very similar fatigue behaviour.

A statistical analysis performed according to Reference indicates that, at a confidence level of 95%, the two populations may be considered equivalent. This observation demonstrates that weld toe geometry has a major influence beyond the effect of misalignment. To better isolate the influence of misalignment, additional test programmes should be carried out in which welding parameters are adjusted to achieve equivalent weld toe geometries. This point deserves particular attention because a significant fatigue improvement cannot be expected from reduced misalignment alone unless it is accompanied by improved weld toe quality beyond the minimum specification requirements.

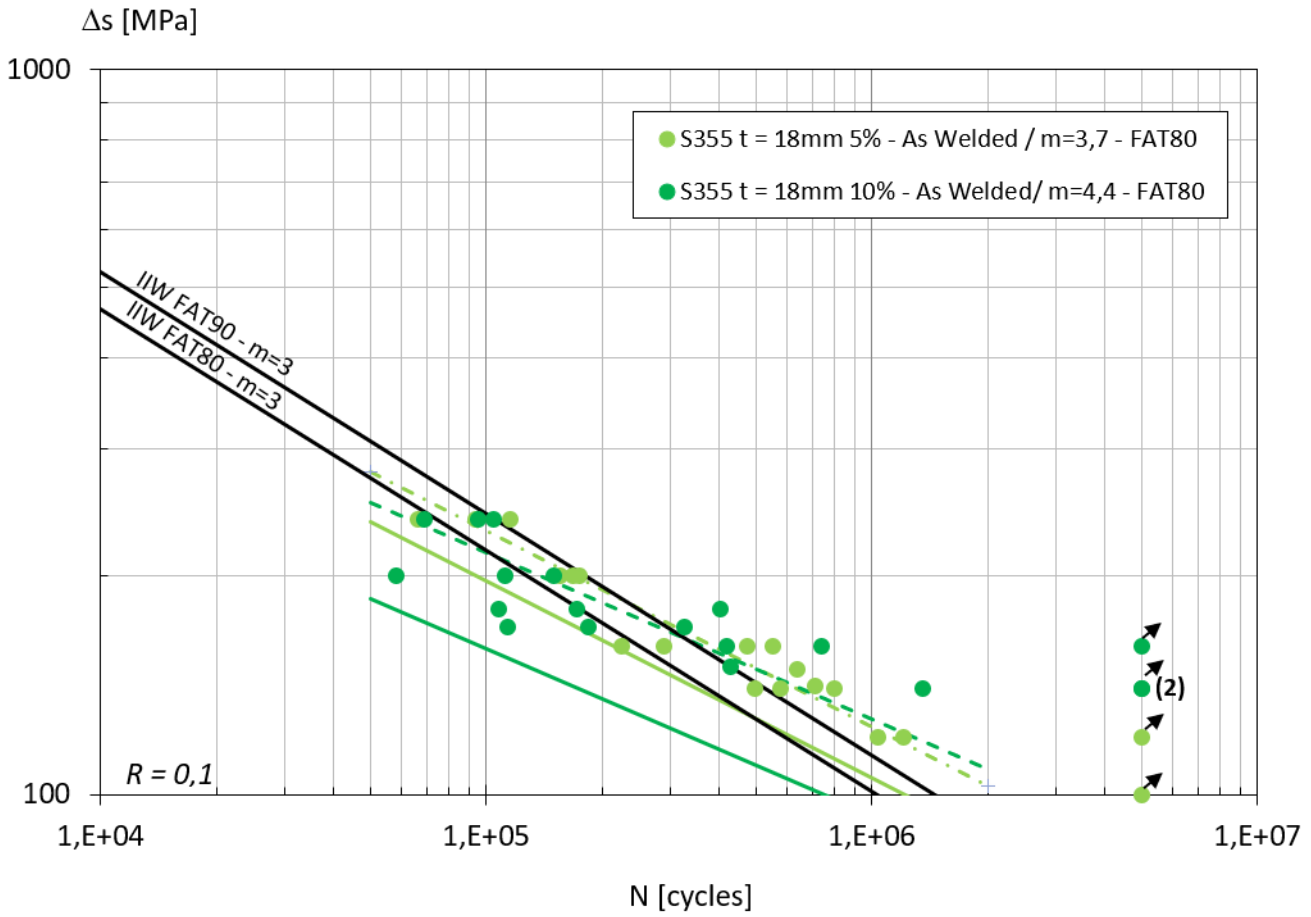


Fig. 4 Fatigue test results for as-welded butt-welded S355 specimens, 18 mm thickness, with 10% and 5% misalignment (dash lines: Ps = 50 % - continuous line: Ps = 95 % with confidence interval of 75%)

It should be noted that, for both specimen series, the expected fatigue classes (FAT80 for 10% misalignment and FAT90 for 5% misalignment) are not achieved at high stress ranges. It should be remembered that the stress concentration effects associated with misalignment are already included in the FAT class definition.

3.2.3. S460 with Weld Toe Burr Grinding, 16 mm Thickness, 5% Misalignment

Fig. 5 shows the fatigue test results obtained on 16 mm thick butt-welded S460 specimens with a 5% misalignment after weld toe burr grinding.

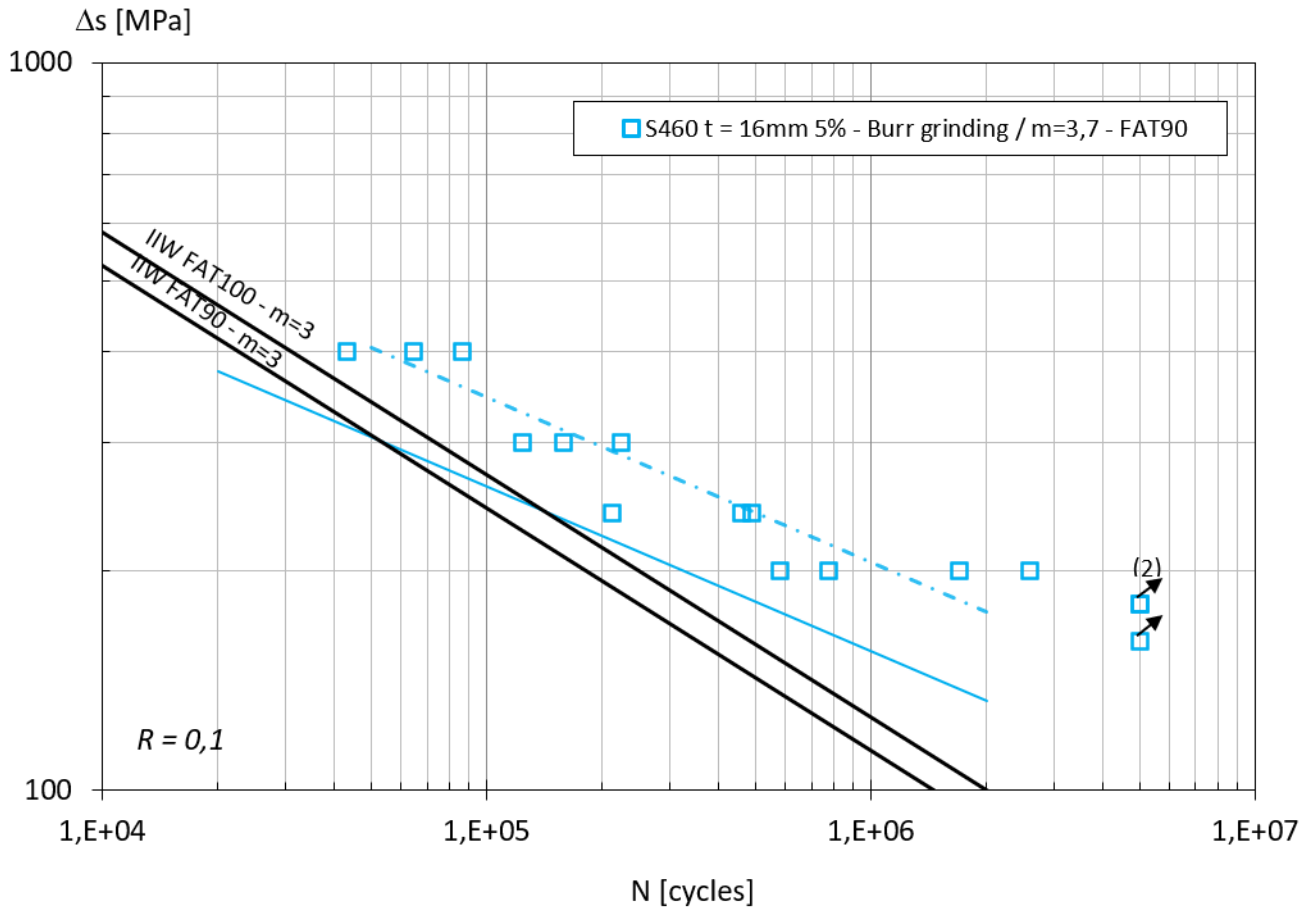


Fig. 5 Fatigue test results for butt-welded S460 specimens with weld toe burr grinding, 16 mm thickness, and 5% misalignment (dash lines: Ps = 50 % - continuous line: Ps = 95 % with confidence interval of 75%)

As observed previously, this specimen series, despite satisfying the requirements associated with FAT B125 according to Annex B of EN ISO 5817, does not reach the expected strength level at high stress ranges. This suggests that the influence of misalignment may not have been fully accounted for when defining this fatigue class. Nevertheless, weld toe burr grinding provides a significant improvement in fatigue performance compared with the as-welded condition.

3.2.1. Fatigue Behaviour After Flush Grinding

Fig. 6 illustrates the influence of weld flush grinding on butt-welded joints manufactured from S355, S460 and S690 steels.

Flush grinding substantially increases the fatigue strength of welded joints compared with the as-welded condition because the weld reinforcement is completely removed, thereby reducing the stress concentration at the weld toe. Furthermore, the slope exponent m of the S–N curves obtained for flush-ground specimens is significantly higher than that of the corresponding as-welded specimens (see Table 7). The resulting values are generally comparable to those typically observed for base materials. The fatigue performances obtained after flush grinding are considerably higher than those currently recommended by IIW.

The fatigue strength observed for S355 appears lower than that obtained for S460 and S690. S690, in turn, exhibits a slightly better fatigue performance than S460.

For the S460 grade, statistical analysis according to Reference indicates that the results obtained for the two investigated thicknesses are equivalent at a confidence level of 95%. Therefore, within the range investigated in the present study, specimen thickness does not appear to influence fatigue performance when results are expressed in terms of stress range.

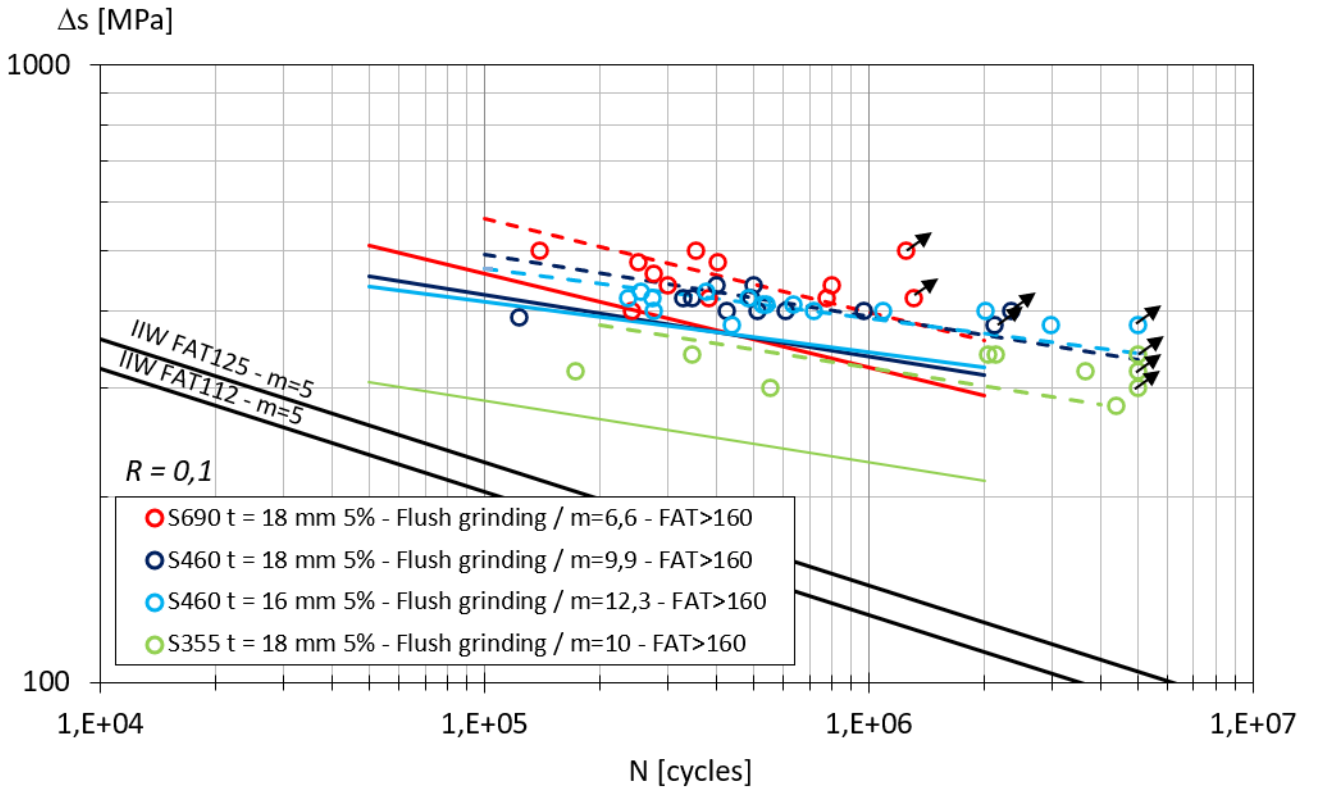


Fig. 6 Influence of steel grade on flush-ground butt-welded joints (dash lines: Ps = 50 % - continuous line: Ps = 95 % with confidence interval of 75%)

3.2.2. Influence of Flush Grinding Compared with Weld Toe Burr Grinding for S460

Fig. 7 compares the fatigue behaviour of flush-ground and weld toe burr-ground S460 butt-welded joints.

Flush grinding significantly improves the fatigue performance of welded joints compared with weld toe burr grinding because both the weld reinforcement and the weld toe geometry are completely removed, resulting in a lower stress concentration factor. Moreover, the S–N curve obtained for flush-ground specimens is considerably flatter than that obtained for weld toe burr-ground specimens (see Table 7).

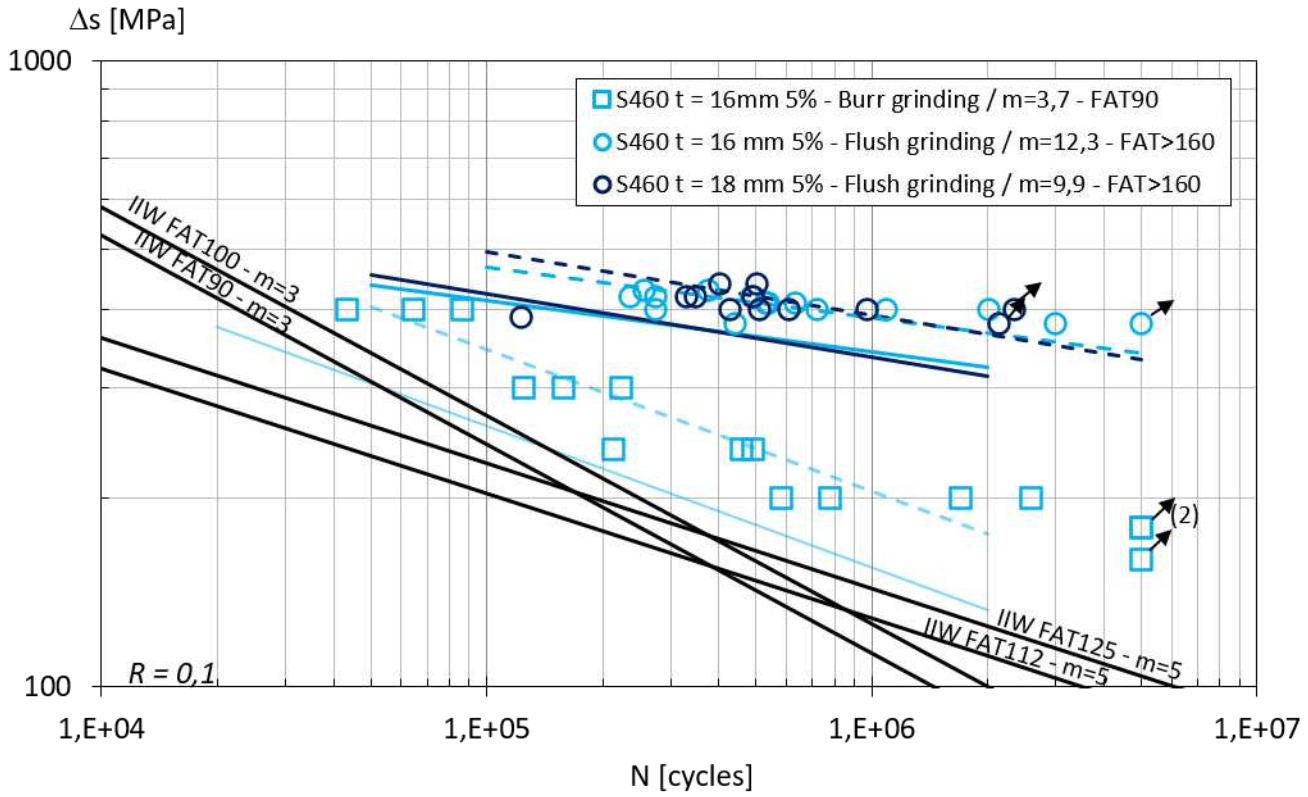


Fig. 7 Effect of flush grinding compared with weld toe burr grinding on butt-welded S460 joints

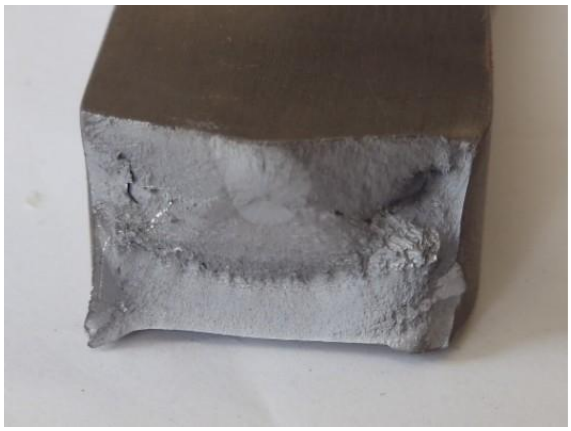
3.3. Fractographic Analysis

For the as-welded specimens, fatigue cracks initiated at the weld toe. In the specimens subjected to weld toe burr grinding, crack initiation occurred within the groove produced by the grinding operation.

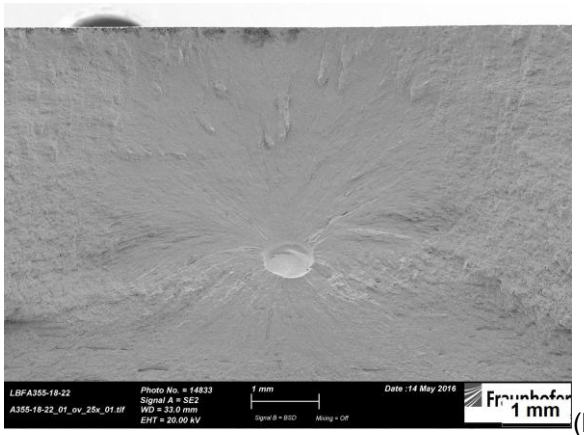
For the flush-ground specimens, a significant number of failures occurred in the gripping area. As a result, only a limited number of valid results, i.e. failures occurring within the welded region, were available for some configurations. Accordingly, all specimens that fractured outside the welded zone were excluded from the analysis.

Regardless of the base material grade—S355, S460 (16 mm and 18 mm), or S690—whenever crack initiation occurred within the welded region, it was frequently associated with weld porosity, as illustrated in Fig. 8 for the specimen A355-18-22. For specimen A460-18-15, the primary crack initiated from a corner of the specimen, while a secondary initiation site developed within the weld metal at the location of a pore (Fig. 9), also near a specimen corner.

It should be noted that all pores acting as fatigue crack initiation sites were smaller than the maximum size permitted by quality level B of EN ISO 5817, namely 0.2 times the welded thickness with an upper limit of 2 mm. Considering the plate thicknesses investigated, the applicable acceptance criterion was therefore 2 mm. The largest pore observed in the present study measured only 1 mm.

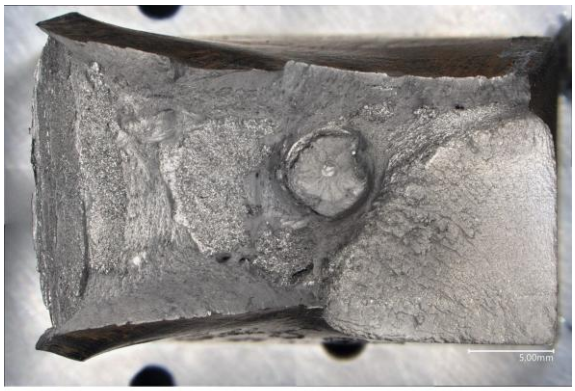


(a)

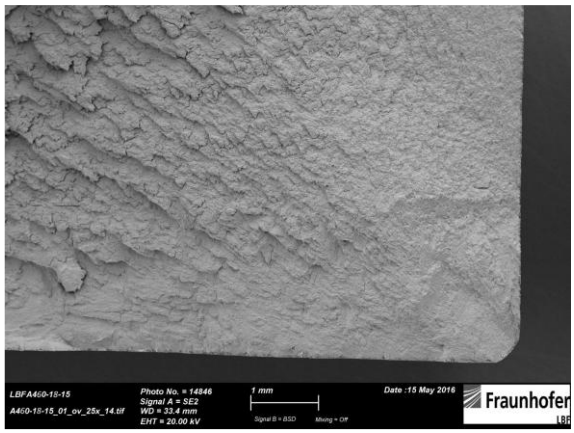


(b)

Fig. 8 Fracture surface of specimen A355-18-22 (Δσ = 340 MPa, N = 2,132,447 cycles), showing fatigue crack initiation from a pore (Fraunhofer LBF)



(a)



(b)

Fig. 9 Fracture surface of specimen A460-18-15 (Δσ = 380 MPa, N = 439,948 cycles), showing crack initiation from a specimen corner (Fraunhofer LBF).

4. Conclusions

To analyse all test results consistently (Table 8), the Basquin's slope exponent was fixed at m = 4 for as-welded joints, as proposed in Project , and for weld toe burr-ground joints. For flush-ground joints, a value of m = 5 was adopted, in agreement with the exponent commonly used for base materials and for flush-ground welds in IIW recommendations . Compared with the previously established curves, an exponent of m = 8, which is more typical of machined steel behaviour, could also have been considered. Since the results obtained for the different thicknesses were statistically equivalent when expressed in terms of stress range, they were pooled together.

Table 8 : Summary of S–N curves obtained after normalizing the Basquin's slope exponent

Steel Grade	Guaranteed YS	Misalignment	Post-weld Treatment	m	log C	FAT
S355	355	10%	None (as-welded)	4	14.357	71
S355	355	5%	None (as-welded)	4	14.411	90
S460	460	5%	Weld toe burr grinding	4	15.197	125
S355	355	5%	Flush grinding	5	18.461	180
S460	460	5%	Flush grinding	5	18.792	225
S690	690	5%	Flush grinding	5	18.792	255

***Note** :*

- *m = 5 for flush-ground welds and m = 4 for all other configurations; log C corresponds to the mean curve;*
- *FAT classes above FAT160 were defined using increments of 12.5%, consistent with the remainder of the FAT scale*.

Using this simplified approach, the following observations can be made:

- The fatigue behaviour of butt welds left in the as-welded condition corresponds approximately to FAT90 for a misalignment of 5%, assuming a slope exponent of m = 4;
- For larger misalignment levels, the experimental result of FAT71 obtained in the present study is slightly lower than the FAT80 class generally associated with misalignments below 10%, even when adopting m = 4;
- Weld toe burr grinding improves fatigue performance without significantly modifying the slope of the S–N curve. The resulting fatigue performance corresponds closely to FAT112, as specified for Detail 211 in IIW recommendations;
- For flush-ground welds, the fatigue strengths obtained are substantially higher than the FAT112 value proposed for Detail 211 in IIW recommendations and even exceed the FAT160 level associated with base material performance. Fatigue strength increases with material yield strength, from approximately FAT180 for S355 to FAT225 and FAT255 for S460 and S690, respectively.

These results clearly demonstrate the importance of weld quality. To improve fatigue performance, particular attention must be paid to plate alignment and to imposed quality requirements that exceed those of EN ISO 5817 Quality Level B. This observation also differs from the approach adopted by IIW regarding the relationship between ISO 5817 quality criteria and fatigue recommendations .

A second important conclusion is that complete flush grinding allows the mechanical properties of HSS grades to be fully exploited. Consequently, plate thickness may be reduced while maintaining equivalent fatigue life. However, this approach requires 100% volumetric inspection of the welds to ensure the absence of internal imperfections, since such imperfections become the primary fatigue crack initiation sites once weld toe stress concentrations are removed. Further investigation of flush-ground welds containing larger porosity levels, while still complying with EN ISO 5817 Quality Level B requirements, would therefore be of considerable interest.

It should also be noted that fatigue performance under real service conditions could be lower than that reported in the present study, since spherical grips were used during testing. For actual structures where deformation at the welded joint is more constrained, fatigue strength may therefore be reduced. Additional investigations would contribute to a better understanding of these effects.

Finally, Figure 10 provides a schematic representation of the potential increase in fatigue class resulting from post-weld improvement methods, allowing comparison with published results on high-frequency mechanical impact treatment (HFMI) and TIG remelting. The following observations can be made:

- For the S460 steel investigated, the fatigue improvement obtained by weld toe burr grinding appears comparable to that reported for TIG toe remelting;

- Flush grinding provides a fatigue improvement greater than that generally reported for HFMI treatments, in agreement with IIW recommendations;
- Owing to the increased Basquin's slope exponent (m = 4–5), post-weld treatments become particularly beneficial at high number of cycles.

In conclusion, post-weld improvement techniques, regardless of the specific method employed, make it possible to take advantage of the yield strength of the base material. The use of higher-strength steels may therefore enable simultaneous reductions in plate thickness and manufacturing costs. This concept has gradually emerged in recent IIW working group activities and should ultimately be incorporated into fatigue design codes. It has already been partially introduced in the 2024 edition of the IIW recommendations for fatigue design of welded joints.

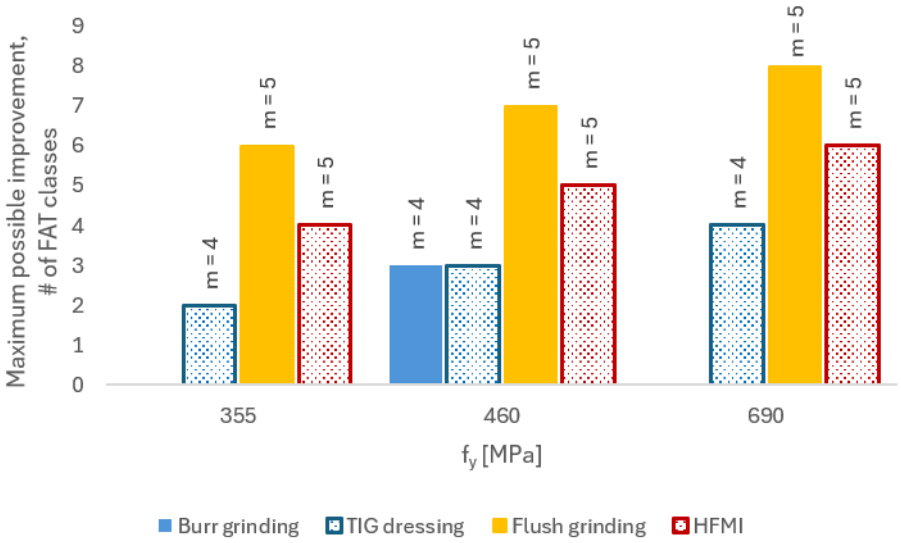


Fig. 10 Potential increase in fatigue class achieved through post-weld improvement techniques relative to a FAT90 butt weld, as a function of base material yield strength.

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7. Declaration of interest

The authors declare that there are no conflicts of interest.

8. Author contribution

L. Jubin : Writing - original Draft, Conceptualization, Formal analysis and investigation
L. Guilmois : Writing – review & editing, Methodology, investigation, conceptualization, Formal analysis and investigation
I. Huther : Investigation, Formal analysis and investigation, Writing – review & editing
F. Lefebvre : Project administration, Supervision, Validation, Writing – review & editing

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